

UNIVERSITY OF TASMANIA

STRUCTURE AND PETROLOGY

OF THE

RAGLAN RANGE

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The Author at Home.

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ABSTRACT

The Raglan Range consists dominantly of pelitic schists, quartzites, and ortho-amphibolites generally of garnet grade. This is the Franklin Group, and overlies Mary Group phyllites of chlorite grade. All are Precambrian.

Precambrian structures show a regional and systematic departure from homoxiality due to a rotation about an axis trending 326° (true), and plunging 24° . This is the expression of Tabberabberan folding. Unrolling about this axis reveals a uniformly gently dipping alternation of schist and quartzite over most of the area.

Two Precambrian deformations are recognisable, here termed S1 and S2. Associated with S1 is the regional metamorphism producing chlorite, biotite, almandine, kyanite in a zonal arrangement. The biotite isograd is taken as the upper limit of the Mary Group. S2 is accompanied by retrograde metamorphism and large scale recumbent folding, during which metamorphic zones were inverted, and the Franklin Group was transported over the Mary Group, possibly in a south-west direction. The Governor River Phyllite, herein defined, is a wide zone of dispersed movement associated with S2. Albite of metasomatic origin crystallised in the interval between S1 and S2.

Quartzites show R-tectonite micro-fabric. The quartz fabric is homogeneous, irrespective of tectonic position, but the mica fabric is unrollable. Lineation in quartzite is due to the intersection of S1 surfaces with an older surface, probably bedding. Lineation in schist is the intersection of the S1 surfaces and axial surfaces related to the S2 folds.

Approximately coaxial relationships between S1, S2 and the Tabberabberan folding permits a construction of a tectonic profile of the Raglan Range by axial projection.

Lamprophyre dykes, probably Tabberabberan in age intrude the schists.

I N T R O D U C T I O N .

This report is concerned with the compositional and structural petrology of a small portion of the Precambrian basement in central western Tasmania. The area, of approximately 27 square miles, is located at the centre of the Lyell Square (58) and encompasses the Raglan Range (S.Lat. $42^{\circ}8'$, E.Long. $145^{\circ}46'$). Access to the centre of the area is readily made by the ~~Kimber~~ track leading to Bradshaw's timber lease which branches south from the Lyell Highway near the mile post, ^ufourteen miles from Queenstown.

The report is the culmination of twelve weeks of field mapping and total of about five months of laboratory work. Rock exposure on the ridge top and in creek beds is good, but on the lower slopes of the ridges, soil covering and thick vegetation completely obscure the geology. Mapping of rock types was made by walking lithological boundaries where possible, and recording on a contour map on a scale of 8 inches to the mile. Approximately 600 foliation and lineation measurements were taken over the whole area. However, in view of the difficult accessibility to the extremities of the area, and the short field season, the sampling of lineation and foliation measurements is not uniform. Conclusions based on statistical arguments are, therefore, not considered to be conclusive.

One hundred thin sections were examined in order to establish the sequence of mineral development in the Franklin Group. Another six oriented thin sections cut normal to the lineation were prepared for petrofabric analysis. The petrofabric diagrams were prepared by plotting (0001) axis of quartz and poles to (001) cleavage in muscovite on the lower hemisphere of Schmidt equal area net, and contouring with a 1% point counter. It is unfortunate that it was not possible to check the petrofabric diagrams for homogeneity from sections parallel to the lineation.

PHYSIOGRAPHY

^{The} Raglan Range rises abruptly to over two thousand feet above the button grass plains of the Collingwood, Nelson and King River Valleys.

The highest point, Raglan Trig. (3,475 ft.) is a small mound ~~sitting~~ on an otherwise flat-topped range. Quartzite forms the backbone of the Range and generally the more resistant quartzite has had an appreciable effect in shaping the land forms. Prominent is Raglan Bluff at the eastern end, where the flat surface suddenly drops ~~to~~ 1100 feet into the Joyce Creek at an angle of 50-60°. The Range is deeply dissected by swift-flowing mountain streams which tend to lie in the softer schists.

The three main creeks in the area, namely the creek flowing west from the disused timber mill, the creek immediately to the east of the mill, and the headwaters of the Governor River are mainly controlled by major faults. The headwaters of the Governor River lie in a vast amphitheatre two miles wide and 1500 feet deep, cut into phyllite and flanked by quartzite. On the north-western rim (marking the line of the Raglan Trig. Fault) is a line of cliffs, 150 feet high, notched into the valley wall. Here, the tributaries flowing off the Range dive over the edge in cataracts before pursuing their course down the valley slopes to join the Governor River. The westerly streams that spill out onto the button grass plains are graded in their lower mountain reaches and tend to meander. These meanders are, however, incised to a depth of 10-40 feet.

Evidence of what is probably the early stages of mountain glaciation is given by three cirques, the positions are shown of the ^{Geological} Map. They occur as pockets high up on the north-easterly face of the Raglan Range. The most easterly cirque (Plate Ia) is the largest and must have contained 1,000 feet of ice when completely full. The base is at 2,600 feet altitude. Both side walls and back wall are steep and the cirque is to a large extent lithologically controlled. The features that point to a glacial origin are:-

- (i) marshy bottom, and hence overdeepened.
- (ii) a polished lip of hard quartz/schist that is now dissected by a small stream.
- (iii) the occurrence of at least 20 feet of fluvio-glacial deposit half a mile down-stream from the lip. This deposit contains poorly-sorted, angular striated boulders Plate Id.

The two cirques further to the west are smaller and situated at an altitude of 2,800 feet. Both are cut into quartzite and exhibit no lithological or structural control. Plate Ib illustrates one of the cirques and the development of a U-shaped valley near the lip. On the lip, polished surfaces with abundant striations are common. (Plate Ic.) ^{lip, polished}

GEOLOGICAL SETTING:

Raglan Range occupies an area on the western edge of the *Pre-* Cambrian block. It is underlain by intensely folded quartzites and schists which received their deformation and metamorphism in the *Pre-* Cambrian (Frenchman) orogeny. At the western edge the metamorphics *rocks* are overlain with angular unconformity by the Ordovician Junee Group. The Junee Group is folded, cross folded and block-faulted - an expression of the Tabberabberan orogeny. The northern boundary of the Raglan Range is marked by large east-west faults which down fault a strip of Palaeozoic sediments. The Nelson and Collingwood River valleys are located in this graben. Two intervening orogenic movements, namely the Penguin Movements and the Jukesian Movements also affected portions of ~~the~~ western Tasmania.

No previous work has been done on the Raglan Range and what little *that* work ^{has} been done on the Precambrian ~~rocks~~ in the Frenchman's Cap area is largely of reconnaissance standard. Adjoinⁱng areas to the south-east and south have been investigated by Spry (1957A) and McLeod (1955) respectively. The area was visited briefly by Spry in conjunction with the H.E.C. West Coast Mapping Campaign in January-February, 1955, who correlated the quartzites and garnet-mica schists with the Franklin Group.

The general findⁱng of Spry (1957A) in the Mt. Mavy area was that the Precambrian structures were refolded in the Tabberabberan Orogeny into the Mavy Anticline. The crest of the anticline trends roughly north-west and is cut by Tabberabberan faults. Effects of the intervening ^{ies} orogeny were not recognised.

S T R A T I G R A P H Y

PALAEOZOIC

JUNEE GROUP:

Owen Conglomerate and Gordon Limestones were mapped by McLeod (1955) along the western margin of the Precambrian craton, unconformably overlying the Fincham Group. The thickness of the conglomerate was given as not less than 130' at Canyon Creek. Gordon Limestone was inferred to overlie the conglomerate but no outcrop was observed by McLeod.

Basal member of the Junee Group:

Angular unconformity between Franklin Group schists and the basal member of the Junee Group of the area occur in two localities. On the south-western side of ^a fault, 400 yards south-west of Bubb's Hill is a pebbly fine grained sandstone dipping at N.E. 30° . This overlies schists which dip north-north-east at about 60° . Specimen 30102 from this locality consists of dominantly quartz, with rounded magnetite (or chromite) grains and interstitial sericite. The average size of this mode is 0.2 m.m. dia. Void space amounts to less than 5% and the quartz grains tend to be interlocked. Well-rounded pebbles of quartzite having a moderate sphericity are scattered in varying quantity throughout the rock. In Slide 30102, the pebble content is approximately 40%.

At co-ordinates 372000 yE, 813500 yN, immediately where that creek flows out onto the button-grass plains, schist dipping 38° toward 268° (true) is overlain by a pebbly fine-grained sandstone dipping 35° toward 282° (true).

The thickness of the sandstone at Bubb's Hill cannot be measured since it is cut by the fault. Bradley (1954, p. 213) gives the thickness of the Owen on the western margin of the craton as 80 feet, although no section is present. At a point 37200 yE, 81400 yN. where the Nelson River flows south between the hills of Gordon Limestone to the west and schists on the east, there exists a gap in the outcrop of about 20 feet. Providing that the sandstone does occur there, and that there is no strike faulting, then the sandstone is about 20 feet thick. Outcrops are very scarce. However, it is expected that the Owen Conglomerate Correlate extends along the western boundary of the block, thinning from about 130 feet in the south to about 20 feet in the north.

Gordon Limestone:

Outcrops of limestone were observed on the western margin of the block where strike and dip measurements are recorded. Limestone also forms the bulk of Bubb's Hill.

PRECAMBRIAN

At this stage where very little is known of the regional structure of the basement Precambrian in Tasmania, any attempts at stratigraphy must be treated with caution. Stratigraphy, even at the group level is suspect because of the presence of major structures which may only be revealed from a detailed investigation of an area having dimensions of the order of 50 miles. Structures such as large recumbent folds or thrusts serve to invert a stratigraphic succession and to considerably change sedimentary thicknesses. Spry and Banks (1955) have indicated that differential degrees of metamorphism and metasomatism will cause time-rock correlates to assume different mineralogical and chemical compositions. Any attempt at stratigraphy based on correlation by lithologic similarity will then be invalid.

The present tentative proposal of group stratigraphy in the Precambrian of the Mt. Mary - Mt. Fincham area is, after Spry:

Fincham Group	quartzite and phyllite of chlorite grade.
Franklin Group	Garnet-mica schists, quartzites and amphibolites of garnet grade.
Mary Group	quartzites, quartz muscovite schists and phyllites of chlorite grade.
Joyce Group	garnet-mica schists, quartzites and amphibolites of garnet grade.

This is a division into metamorphic facies. It will be shown that the Fincham quartzite, in all probability grades along strike (bedding) into the Franklin Group and correlation by structural continuity indicates that the Fincham quartzite is not younger but equivalent to the Franklin Group. Similarly, the Mary Group appears to grade across the strike into the Franklin Group.

The apparent succession in the Raglan Range area is given as :

Franklin Group Quartzite and schist

Mary Group

Biotite-albite phyllite

It is not suggested that this is a stratigraphic succession and the term "group" is used for an assemblage of metamorphic rocks having essentially the same metamorphic facies and the same degree of structural deformation.

Spry pointed out (1955A, p. 88) that stratigraphy on the formation level is even more difficult, mainly because the repetition of rocks of identical lithology results in the inability to correlate by lithological similarity. However, if it is accepted that this major repetition represents bedding then a stratigraphical succession can be arrived at for any one area by detailed field mapping followed by structural correlation.

This, in effect, amounts to walking the outcrop which yields a rock and a rock-time unit of correlation. In the absence of sedimentary structures, or the knowledge of the major structure, it will not be possible to determine the facing of that succession.

Mary Group:

Spry (1957) defined the Mary Group as that "group of quartz schists, massive quartzites and phyllites which occur on Mt. Mary, and in the area between the Mary Creek Plain and the Franklin River". Schistose and massive quartzites and phyllites also occur in the adjacent Mt. Fincham Map Square to the west (McLeod 1955). These are structurally continuous with the Mary Group as defined.

In the Raglan Range area, the same rock types occur in a wedge $1\frac{1}{2}$ miles long, which tapers in a north-easterly direction to a point where it is cut by a N.W. fault (2,000 feet from Raglan Trig.) The broad end of the wedge is terminated by a major east-west fault. Similar quartzites and quartz-muscovite schists also occur on the southern side of this fault.

These rocks are correlated with the Mary Group on the following grounds:-

1. Mineralogical and petrographical identity with the Mary Group in the type area.
2. Rocks on the southern side of the major east-west fault appear to be structurally continuous with the Mary Group mapped by McLeod (1955).

3. The Mary Group is overlain by the higher grade Franklin Group in the Mt. Mary area, and also in the Raglan Range area.

Spry considered (1957A) that the Mary Group overlies the Joyce Group with probable unconformity and is overlain by the Franklin Group with possible unconformity.

The apparent succession of the Mary Group in the Governor River area is :-

	Thickness feet
Franklin Phyllite	
Mary Quartzite	30
Phyllite	250
Quartzite	30
Quartz-muscovite schist	160
Phyllite	250
Quartzite	100
Phyllite	500
Quartzite	80
Phyllite	660
Quartzite	330
Biotite-albite phyllite	
	<hr/>
Total Mary Group ...	2,390 feet
	=====

The lithologic types probably represent original sedimentary units. Isoclinal-recumbent folding is visible on all scales, and exposure is poor, so that the effects of large-scale folding on the thickness of beds, and on the succession itself is unknown.

The Mary Group is overlain and underlain by fine-grained biotite, albite and/or garnet bearing phyllites. The lower contact is between quartzite and these phyllites, and although mostly covered by vegetation, foliation measurements that could be obtained give no evidence of disconformity. The top phyllite overlies all members of the Mary Group succession in a manner shown in the tectonic profile. (Fig.12).

The possible nature of this contact is either a disconformity, a low angle fault and a metamorphic contact. Evidence supporting a gradational metamorphic contact, oblique to the bedding will be given later.

FRANKLIN GROUP:

The Franklin Group is defined (Spry 1957A) as "those schists and quartzites lying below the Fincham Group and above the Mary Group and outcropping between the Franklin River and the Engineer Range west of Frenchman's Cap." The quartzite and schists of the Raglan Range are correlated, on structural and lithological grounds with Franklin Group rocks to the south.

The Raglan Range is underlain by quartzite, micaceous quartzite, quartz-muscovite schist with or without garnet albite biotite and amphibole, phyllite and amphibolite. The lowermost unit of the Franklin Group in this area is called the Governor River Phyllite. It is here defined as

that phyllite lying structurally above the Mary Group and below the remaining portion of the Franklin Group, occurring on the northern slopes of the Governor River Valley, Raglan Range. Both its upper and lower boundaries are gradational and the thickness varies between 1,000 and 4,000 feet. The lithology is described on page 2. Rather than a stratigraphic unit, it appears to be a tectonic slab which received its distinctive lithology and fabric when the Franklin Group moved over the Mary Group.

The Governor River phyllite resemble a phyllonite in texture and structural setting. McLeod was able to make this division of the Franklin Group in the Mt. Fincham area. The Governor River phyllite is similar in lithology and structural position to his Canyon Creek type schist.

With the demonstration of recumbent folding in the upper part Franklin Group, stratigraphic sequences are deducible on a small scale but with unknown facings. However a glance at the tectonic profile Fig. 12 will show that at this stage, the recording of stratigraphic sequences is pointless.

Fincham Quartzite:

The Fincham Group was mapped by McLeod (1958) from the Engineer Range north to the Governor River forming the prominent ridge which includes Mt. Fincham and Mt. Maude. This line of hills continues northward from the Governor River for a distance of three miles. The quartzite forming

these hills is structurally continuous with the Fincham Group but are petrologically different. (Page 39). The quartzite slab is 1900 feet thick immediately north of the Governor River, and pinches out three miles to the north.

Structural and petrological evidence indicates that these quartzites are an integral part of the Franklin Group, which most probably grade southward into typical Fincham Group quartzite.

L A M P R O P H Y R E D Y K E S

Basic intrusive rocks were first reported from the Raglan Range by Spry (1957). The lamprophyres form tabular and steeply dipping bodies discordant to the foliation in the intruded schists. They are found to vary from 1 to 15 feet in thickness and their horizontal and vertical extent is not known. Because of their extreme susceptibility to weathering, exposures are only found in creek beds and in the track cuttings. The localities are shown on the map. At the southern-most locality are three parallel dykes connected by thin feeder sills. The dykes tend to form in a swarm alongside a major Tabberabberan fault; the trend of the dykes is also in this direction.

Petrology:

Creek exposures are fresh, but the road exposures are reduced to a tan-coloured clayey mass. A specimen suitable for chemical analysis No. 30103 was, however, extracted from the core of a large spheroidally weathered kernel. The fresh rock is dark green, fine-grained speckled with dull black ferro-magnesium phenocrysts.

Specimen 30103 has a mineral composition of quartz 3.2%, plagioclase 23.6%, clinopyroxene 28.3%, amphibole 12.9%, biotite 2.3%, ilmenite 3.9%, all of which are primary, and

talc 5.8%, calcite 4.0%, chlorite 15.6% and leucoxene which are secondary. The chemical analysis and the norm are given in table I.

The pyroxene is colourless, optically + ve with a 2V of approximately 60° and an extinction angle \wedge^c of 54° . It is of the augite variety and the norm indicates it is deficient in lime.

The amphibole is pleochroic from brownish yellow to dirty greenish-yellow. It is optically -ve. with a 2V of approximately 50° . It is characterised by third order green maximum interference colours and an extinction angle from 0 to 5° . It thus resembles lamprobolite. A labradorite - bytownite plagioclase ($Ab_3 An_7$)^{is} indicated by the norm.

The rock (30103) is porphyritic, phenocrysts of amphibole and clusters of clino-pyroxene are scattered in a fine ground mass of plagioclase, quartz and chlorite. Clinopyroxene occurs in sub-hedral to euhedral short prisms with 8-sided cross sections. They range in size from 0.2 m.m. to 1 m.m. diameter forming clusters of crystals up to 2 m.m. in diameter. Along borders and fractures, the pyroxene is replaced by secondary green amphibole. Phenocrysts of amphibole average 0.8 m.m. in diameter, and range up to 2.3 m.m. They form stout prisms invariably with reaction rims of talc. The larger phenocrysts show the original grain shape, the medium ones are usually skeletal

remains whilst the smaller crystals are completely replaced appearing as fluffy patches of fine fibrous talc.

Compared to the amphibole, pyroxene is relatively fresh.

Phenocrysts comprise 45% of the slide.

The ground mass consists of interlocking small tabular needle-shape laths of plagioclase, subhedral pyroxene and anhedral chlorite flakes with interstitial quartz. The average length of the plagioclase is 0.1 m.m. Biotite occurs in ragged shreds, partially chloritised, up to 0.3 m.m. in length. Minute grains and aggregates of grains of calcite^{are} clustered around small pyroxene crystals.

Ilmenite and magnetite are ground-mass accessory minerals.

The norm indicates the presence of orthoclase. However, the ground mass is chloritised and sericitised so that it is not possible to identify it. The plagioclase laths have a flow texture around the phenocrysts, and biotites are usually bent.

Specimen 30104 is^a slightly different variety, in that hornblende is the dominant phenocryst. It contains 32.7% hornblende, 7.8% clinopyroxene, 5.7% actinolite; all of which occur as phenocrysts, and 49.0% chloritised - sericitised ground mass, 2.6% calcite and 2.2% iron ores.

Hornblende phenocrysts are sub-hedral slender prisms up to 2 mm. long. It is a coloured variety (X = light greenish yellow, Y = light olive green, Z = moderate olive

brown), optically-ve with a 2V of about 60° and $Z^{\wedge}C$ of 21° . There is no hydrothermal alteration of the hornblende. Fibrous aggregates of serpentine form equidimensional phenocrysts up to 2 m.m. in diameter. The serpentine is slightly pleochroic between pale green and yellow-green and has upper first order interference colours. The fibres tend to be arranged in two lines at 60° and may represent pseudomorphs after amphibole. Phenocrysts of clinopyroxene (augite variety) are present. These are fractured and fragmented but chemically unaltered crystals.

The ground mass is more altered than in 30103 and it consists of an interlocking mesh of sericitised plagioclase, quartz, chlorite, microlithic hornblende with a little biotite, magnetite and ilmenite.

A feature of the slides examined is the common association of altered and relatively fresh ferro-magnesian phenocrysts. This may indicate a hybrid origin of the lamprophyre in which case the norm would not agree with the mode. ~~Corundum~~ Corundum, present in the norm does not appear in the mode and amphibole is present which may be connected with the high concentration of volatiles.

<u>Norm</u>		<u>Mode</u>	
Quartz	2.9% by wt.	Quartz	3.2 by vol.
Orthoclase	5.0%	Plagioclase	23.6%
Ab ₃ An ₇	25.3%	Amphibole	12.9%
Corundum	2.9%	Clino- pyroxene	28.3%
Hypersthene	49.4%	talc	5.8%
Magnetite	2.3%	chlorite	15.6
Ilmenite	1.4%	ilmenite	} 3.9%
Apatite	0.3%	magnetite	
Calcite	4.2"	calcite	4.0%

The rocks belong to the camptonite-spessartite series of Johannsen's classification of lamprophyres, since they are characterised by the presence of plagioclase with pyroxene and amphibole in varying proportions. The chemical composition of specimen (30103) is compared with the gross average chemical composition of mineralogically similar lamprophyres (Table I).

TABLE I.

	1	2	3	4
SiO ₂	46.16	53.52	50.79	45.17
Al ₂ O ₃	12.7	14.57	15.26	14.78
Fe Fe ₂ O ₃	1.58	3.52	3.29	5.10
FeO	9.51	5.29	5.54	5.05
MgO	12.79	6.60	6.33	6.26
CaO	6.12	7.03	5.73	11.06
Na ₂ O	0.94	3.48	3.12	3.69
K ₂ O	0.80	2.28	2.79	2.73
H ₂ O	5.61	1.75	5.71	3.40
CO ₂	1.93	-	-	-
TiO ₂	0.71	1.25	1.02	1.90
P ₂ O ₅	0.13	0.34	0.35	0.51
MnO	1.31	0.38	0.07	0.35

- 100-28
 1. Specimen (30103) Raglan Range
 2. Gross average spessartite
 3. " " kersantite
 4. " " camptonite

Analyses

2. 3. 4. taken from Barth, 1951. Theoretical Petrology

These analyses are compared on a (Na₂O + K₂O) - MgO - FeO ternary diagram (Fig. 1). There is a considerable difference

Ternary diagram illustrating similarities between

1. Raglan Range lamprophyre
2. spessartite (Bouch)
3. kersantite (H)
4. camptonite (H)

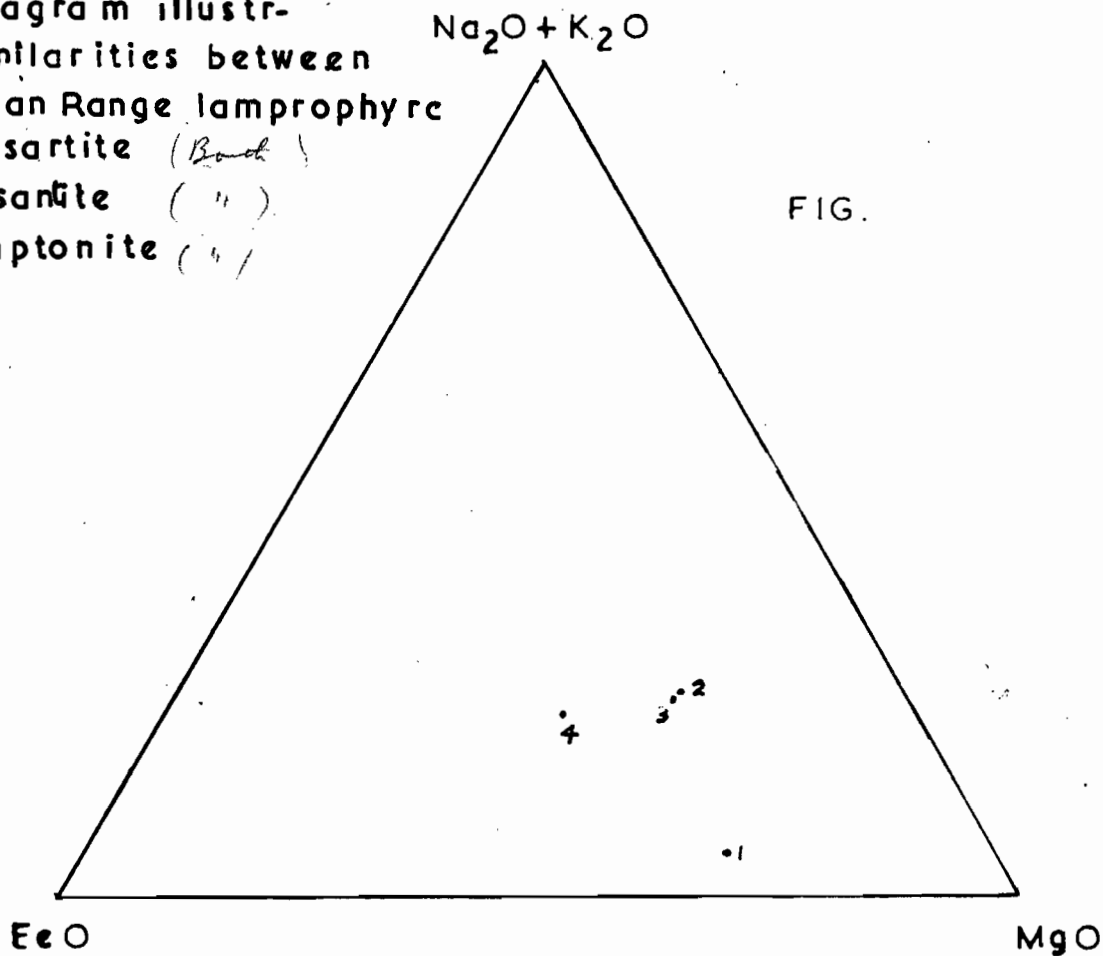


FIG.

FIG. 1

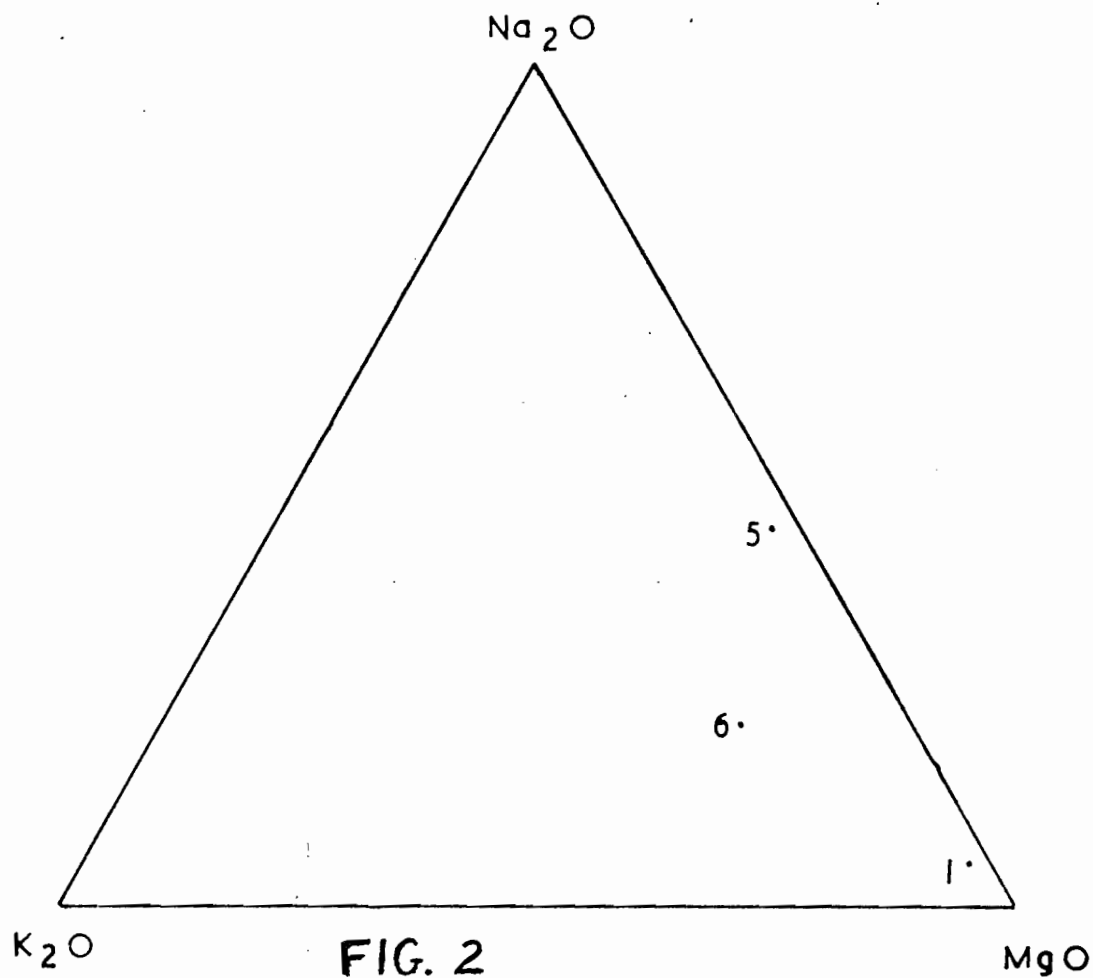
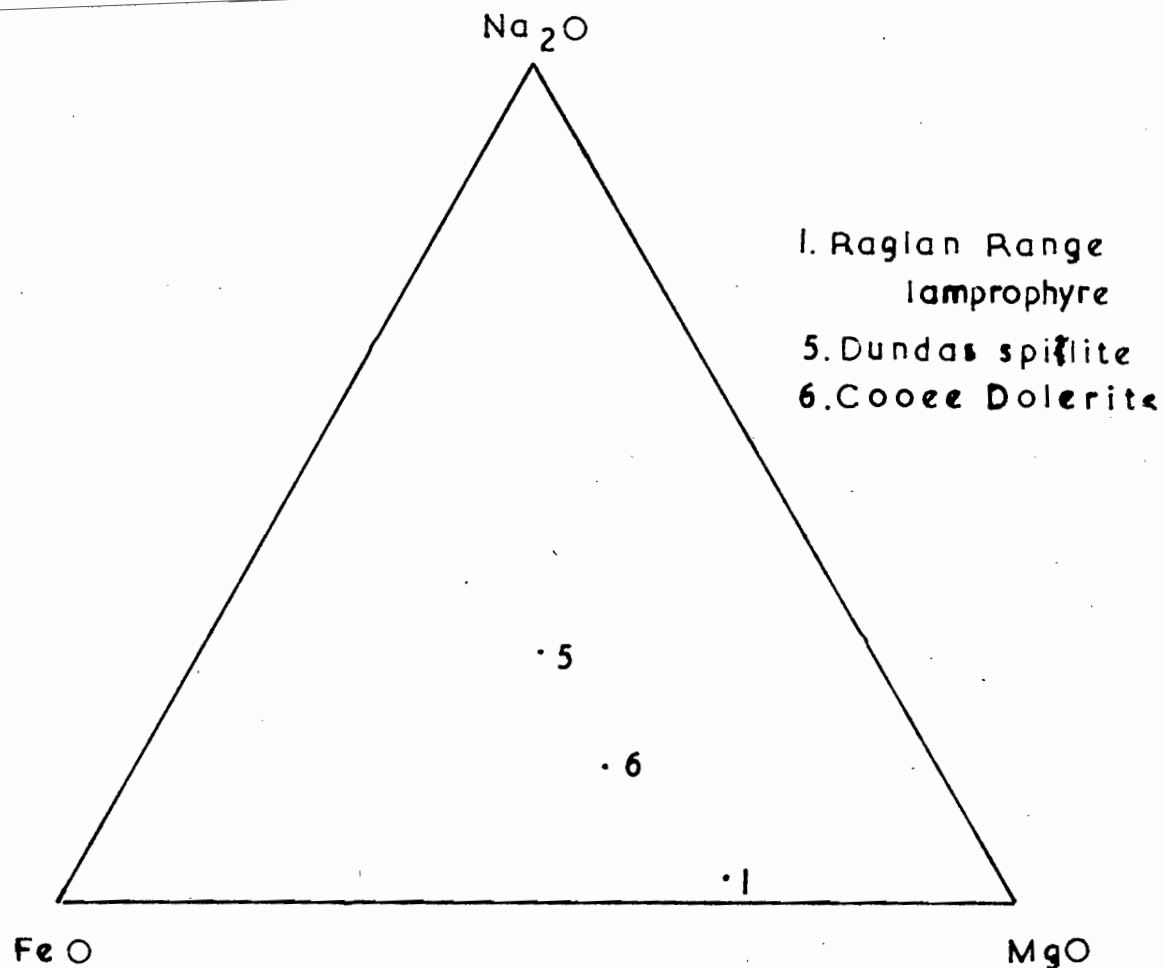


FIG. 2

between specimen (30103) and the camptonite, but it differs from spessartite only in the lack of alkalis. Other similarities are the high CaO and H₂O content.

A tentative correlation between the basic intrusions on the Raglan Range and the Coosue Dolerite was made by Spry (1957A). The lamprophyres are texturally and chemically dissimilar to the dolerite. The average composition of the dolerite is plotted, along with the lamprophyre on Na₂O - FeO - MgO, and ^{Na₂O - K₂O -} MgO - MgO ternary diagrams to demonstrate the differences (Fig. 2). Also included is the average Dundas spilite (from Spry 1957B).

Field indications are that the lamprophyres intrude parallel to a major Tabberabberan fault line. The nearest lamprophyre outside the Raglan Range occurs at Mt. Lyell (pers. comm. M. Solomon) which are Tabberabberan in age. Specimens were examined from Mt. Lyell and seem to be texturally and mineralogically similar to those on the Raglan Range.

MINERALOGY

Mineralogically, the Franklin Group ~~are~~ simple; muscovite, quartz, primary chlorite, almandine and albite are the dominant constituents, with biotite and kyanite, amphibole and zoisite as essential but minor components. Accessory minerals include tourmaline, zircon, rutile, sphene, apatite, pyrite, ilmenite, magnetite.

No attempt was made to examine any regional variation in the compositions of individual minerals.

MUSCOVITE

Muscovite occurs in flakes which define the tectonic surfaces, and as inclusions in the albite. It is optically -ve and two measurements of 2V are 33° and 38° . An X-ray powder photograph was taken, giving the following results:

<u>Line</u>	<u>Intensity</u>	<u>d-Spacing</u>
" 1	VS	9.99 \AA°
2	M	5.00
3	M	4.51
4	S	4.28
5	W	4.10
6	W	3.93
7	W	3.73
8	W	3.50
9	VS	3.36
10	M	3.21
11	M	3.00
12	W	2.88
13	S	2.59
14	W	2.47
15	W	2.29
16	M	2.19
17	W	2.00
18	W	1.67

The d-spacings compare favourably with a Muscovite 2M structure. There is no evidence of the mica being the paragonite end member.

GARNET

The garnet is the almandine variety. It is pale pink coloured when cleaned with acid, and has a refractive index of 1.801. The x-ray data are:

<u>Line</u>	<u>Intensity</u>	<u>d-Spacing</u>
1	VS	2.88
2	VW	2.58
3	VW	2.45
4	M	2.35
5	M	2.26
6	W	2.16. — ? 2.102 not 2.16
7	S	1.87
8	M	1.66
9	S	1.60
10	S	1.54
11	W	1.44
12	M	1.29
13	W	1.26
14	VW	1.23
15	M	1.07
16	W	1.05
17	W	1.02
18	VW	0.95
19	M	0.93
20	W	0.86
21	W	0.79
22	W	0.78

These readings give a cell size of 11.55 \AA . Fleischer (1937) and Skinner (1956) give values of 11.518 and 11.526 respectively for the almandine end member. Skinner also reports a value of 1.830 for the r.i. of almandine. The value of A° is slightly, but significantly higher than Fleischer's or Skinner's

and indicates a solid solution of almandine - pyrope - (probably) grossularite, with almandine as the dominant component.

ALBITE

No optical properties of the mineral using universal stage were made, however, it is intended to determine the plagioclase accurately in the near future.

The polysynthetic and simple (Carlsbad?) twinning, the negative relief, and the porphyroblastic habit together are a strong indication that the plagioclase is albite.

CHLORITE

Two types of chlorite are present.

- (i) Primary chlorite that has crystallised as such and not an alteration product of a pre-existing mineral. This occurs in sub-idioblastic flakes forming usually fan shaped aggregates. It is pale yellowish green, non pleochroic. It is weakly birefringent, $n_y - n_x$ is about 0.008, the biaxially +ve with a $2V$ of about 10° . The chlorite has the properties of prochlorite.
- (ii) Secondary chlorite which has replaced garnet. It occurs in small, equidimensional flakes, in some places hexagonal. It is pleochroic from apple green to colourless, shows anomalous "Berlin blue" interference colours in longitudinal section and

is isotropic in basal section. One interference figure obtained was uniaxial -ve. It resembles penninite.

BIOTITE

Biotite is a minor but common constituent of the Franklin Group. Brown biotite is the only type present. It is strongly dichroic from dark reddish brown to almost colourless and slightly biaxial.

AMPHIBOLE

Amphibole occurs in sub-idioblastic and poikiloblastic broad prisms. It is optically -ve with a $2V$ $70^\circ - 80^\circ$ (approximately), and a maximum^{um} extinction angle ($Z \wedge C$) of 20° . The pleochroic formula of the amphibole in specimen ³⁰¹³² ~~18~~ is X = pale green, Y = yellow green, Z = light blue-green. The pale colour suggests actinolitic amphibole, but the crystal form is more in keeping with hornblende. In the absence of a refractive index measurement and chemical analysis, it is tentatively proposed that the amphibole is a actinolitic - hornblende possibly with a small amount of Na_2O .

KYANITE

Small clusters of kyanite fragments are present in slides ³⁰¹¹⁷ (23) and ³⁰¹³³ (45). It is recognised by its high relief, the prismatic cleavage and the basal parting. The interference colours are first order yellow and red, and the extinction angle and $2V$ is consistent with kyanite.

P E T R O G R A P H Y

MARY GROUP:

Quartzites, quartz-muscovite schists, and phyllites comprise the Mary Group in the area. Mineralogically, this group is simple, containing quartz, muscovite, sericite, occasionally chlorite and accessory rutile, zircon and tourmaline.

Phyllite -

The phyllites are extremely fissile, medium to dark gray rocks, often with a pearly lustre (e.g. 30105, 30106). The fissility is due to an alternation of thin bands (0.5 m.m.) of alternating quartz and muscovite rich layers. Quartz is the dominant component, with muscovite forming between 20-50%. Quartz grains average 0.15 m.m. dia., but can be as small as 0.30 m.m. diameter. The muscovite is often dirty with iron staining and dusty graphitic^t inclusions. Muscovite flakes vary in length from 0.2 to 0.03 m.m.

Quartz-muscovite schists -

Specimens 30107 and 30108 are moderately fissile light gray glossy quartz-muscovite schists. They differ from the phyllites in that the muscovite is less in quantity (approximately 25%) but is larger in size and also clearer. Muscovite occurs in sheaths composed of slightly green flakes up to 1 m.m. long. Rutile appears to be more common

than in the phyllites. Specimen 30109 is a schistose micaceous quartzite containing spindle-shaped porphyroblasts of chlorite (*penninite*) 1 m.m. long, and elongated in the direction of the lineation.

Quartzite -

The quartzites are fine-grained, often saccharoidal gray to light gray, finely-banded rocks. This banding is parallel to a layering which is seen in Plate IVf. This layering is due to massive and fissile varieties of quartzite. A plane of parting, due to orientation of muscovite is also parallel to the banding. No ripple marks or cross bedding were observed, but these structures have been reported by Spry (1957 A) from the Mt. Mary area .

The quartzites contain not more than 10% muscovite. Specimen 30110, the grain size is non-uniform, varying from 0.1 m.m. to 0.01 m.m. diameter. The larger grains are more or less equant but have irregular edges and are separated from each ^{other} by a matrix of finer quartz, muscovite and a little chlorite. Muscovite is very small (0.02 m.m. long) and shows a strong degree of preferred orientation (Diag. D10). Deformation lamellae are common in the larger quartz grains.

The two grain sizes are more apparent in specimen 30111. Irregular grains, 0.3 m.m. diameter, having undulose extinction and feathery and jagged edges from 60% of the slide. The remaining matrix consists of a cloudy mass of very fine sericite, granular quartz and broken muscovite flakes. Generally, the muscovite is oriented in the plane of the banding. The banding is due to trails of graphite.

Evidence of shearing and granulation is recorded in the texture. Quartz grains are not usually in contact, but isolated aggregates of fractured quartz grains which are in mutual contact probably represent an intermediate stage in the granulation of the original rock. The nature of the original rock is uncertain. It may be either a sheared sediment (sandstone) in which case the quartz grains are the remains of the original clastic particles, or it may have resulted from the mechanical breakdown of a previous fabric by fragmentation, followed by granulation along grain boundaries. If the graphitic banding is original bedding, then, it is probably the former case.

FRANKLIN GROUP:

Although the description of the mutual relations of the constituent minerals, and the relationship between minerals and tectonic surfaces is purely petrographic, the study affords evidence on the crystallization history and its

relation to the tectonic history. For this reason the subject is deferred to Relationship between Deformation and Metamorphism.

The section that follows involves an outline of the main rock types and petrographic descriptions of the more unusual rock types.

Governor River Phyllite -

The Governor River Phyllite consists mainly of fine-grained dark-gray to black phyllites. Other interbedded rock types include schists similar in lithology to the coarser Franklin Schists, and fine-grained banded quartzites similar to those in the Mary Group.

The phyllite underlying the Mary Group (coordinates 810000 yN, 381000 E)) appears to be identical in petrography and mineralogy to the Governor River Phyllite.

Quartz, muscovite and albite are the more common constituent minerals. Biotite and garnet are present in quantities not more than 10%, and tourmaline, graphite, pyrite, apatite and zircon are accessory minerals. Secondary chlorite and limonite are present, usually replacing garnet. The lower part of the formation, indicated by that portion lying below the garnet isograd is devoid of garnet.

Specimen 30112 is a typical phyllite, steel-gray in colour, slightly glossy. Only in thin section can constituent minerals be identified. A point count gave a

composition of quartz 45.1%, muscovite 30.2%, albite 21.1%, biotite 1.8% and tourmaline + pyrite + rutile 1.8%. The rock has a schistose texture due to alternating quartz and muscovite rich layering. Quartz grains are interlocking and average 0.1 m.m. dia. Albite is porphyroblastic with an average diameter of 0.5 m.m. Muscovite is dirty with minute graphitic inclusions.

Specimen 30113 differs from 30112 in that it is slightly coarser and contains garnet. The mineralogical composition (from 1000 points) is quartz 49.3%, muscovite 23.4%, albite 15.1%, biotite 6.7%, garnet 5.1%, tourmaline + rutile + iron²ides 0.4%. The average sizes of the quartz grains and porphyroblasts of albite and garnet are 0.3 m.m. and 0.5 m.m. dia. respectively.

Quartzite interbedded with the phyllite is recorded at two localities (See Geological Map, Fig. 13). In hand specimen it is similar to those fine-grained gray and white banded quartzites in the Mary Group. Microscopically, specimen 30114 differs from the Mary quartzite in that it contains plagioclase (probably albite) and the muscovite flakes are larger, varying in length from an average of 0.2 m.m. to a maximum of 0.5 m.m. Plagioclase (albite?) is recognisable by its cloudiness, lower relief than quartz, and an optically + Ve sign with a 2V of about 80°. It contains inclusions of quartz and is speckled

with sericite. Quartz and albite are about equal in size and form an interlocking mosaic. The albite is present in the slide in proportions varying from 50% to 10% and thus producing a compositional banding which appears parallel to the mica cleavage-plane foliation.

FRANKLIN GROUP: (excluding Governor Giver Phyllite)

This assemblage consists mainly of thick, alternating slabs of quartzite and schist in approximately equal proportions. Petrographically there are all gradations between schist and quartzite. The transitory rock type usually occur in units up to 20' thick at the junction between schists and quartzite. The term schist is used for the rock of pelitic composition containing more than 50% or more micaceous mineral. Quartzite is restricted to the psammitic rock containing less than 20% micaceous mineral. Micaceous quartzites occur in the intermediate field.

(a) Pelitic Rocks -

The most common type of schist is the quartz muscovite schist which contain only small amounts of albite and garnet. These schists are dark-grey, coarse-grained with distinct foliar, 1 - 2 m.m. thick and small red pellets of limonite representing altered porphyroblastic garnet. Specimen 30114 is a typical example; the essential minerals of which are muscovite 46.5%, quartz 39.3%, garnet 6.6% and albite 6.3%.

Commonly these quartz-muscovite schists are interfoliated with, and grade along the strike of the foliation into albite schists. One example (30115) is a dark grey-green, coarsely knotted schist containing round albite porphyroblasts up to 1 c.m. dia. Porphyroblasts occupy about 60% of the rock. The ground mass consists of flakes of muscovite (2 - 3 m.m. long) which wrap round the albite, and interlocking quartz (0.5 - 1 mm. dia.). A similar specimen (30116) contains albite porphyroblasts 44%, quartz 22%, biotite 20%, chlorite 13.0% and accessory minerals 2.0%.

Biotite is a common constituent in the schists but rarely exceeds about 5%. However, schists in which the place of muscovite is taken by biotite do occur on certain horizons. The petrology of the biotite schists, and their relation to the amphibolites are discussed on p. 46.

(b) Psammitic Rocks -

Psammitic rocks usually contain minerals such as garnet, hematite, muscovite, chlorite, albite and biotite. The main rock types are quartzite (less than 20% micaceous mineral), garnet quartzite and micaceous quartzite.

Quartzite is by far the dominant psammitic rock type present. The quartzites are well-foliated and banded, rarely massive rocks, clean white on weathered surfaces but usually a dirty brownish white on freshly cut faces. A

30137
 typical specimen (~~63~~) contains quartz 84%, muscovite 8%,
 biotite 3%, garnet remnants 4%, and apatite + tourmaline 1%.
 The quartz grains (average size 0.3 m.m., maximum size 0.8
 m.m.) form an interlocking mosaic peppered with remnant
 garnet porphyroblasts. The garnet averages 0.7 m.m. dia.,
 is included with quartz, and is partially replaced by hematite
 and limonite. Muscovite occurs in iron-stained, small
 (0.3 m.m. average length) ragged flakes aligned in the
 foliation surface. Commonly, the mica that wraps around
 the garnet is brown pleochroic biotite. Muscovite occurs
 in iron-stained small (0.3 m.m. average length) laths and
 biotite is in the form of short stumpy ragged flakes. Green
 and blue tourmaline, and dimensionally orientated needles of
 apatite are scattered throughout the slide. Specimen 30117
 is a similar quartzite but contains spindle-shape aggregates
 of chlorite (prochlorite) as well as muscovite orientated
 parallel to the foliation.

It is common to find planes of liquid inclusions
 in the quartzites. These are either in more or less straight
 parallel trails, or are in two sets intersecting at about 30°
 making a large angle with the foliation. In specimen 30118,
 a coarse-grained fairly pure quartzite, these planes can be
 seen to originate from a discrete crack cutting a finer-
 grained band. From this crack the trails splay out like a
 horse-tail. Tuttle (Fairbairn 1949, p. 68) interpreted

these as deformation phenomena. The grains are cut by a planar fracture, which is then filled with hydrothermal liquid. Differential solution and deposition seals the fracture leaving a plane of liquid inclusions.

On the ridge trending south-east from Raglan Bluff, interbedded with the normal quartzites is a band of garnet quartzite passing along the strike into chlorite-garnet quartzite. The position of the band is shown on the geological map.

The garnet-quartzite is medium gray in colour, vitreous to saccharoidal, knotted with fresh and hematite altered garnet. Slide 30119 contains about equal proportions of quartz and garnet (80%) with biotite, fine muscovite, chlorite, apatite and hematite constituting 20%. The garnet is quite fresh, an average of 0.8 m.m. diam., and cut by two sets of closely spaced cracks normal to each other. Where intact the garnet is euhedral, but more commonly it is fragmented and disaggregated. The quartz grains average 0.5 m.m. diam., the larger grains measure 1.0 m.m. diam. Brown biotite occurs in sub-idiomorphic broad flakes butting against, and interstitial to garnet. Inclusions of quartz and garnet are common, and some of the flakes are even idio-blastic. Biotite does not show any preferred orientation. Specimens 30120, 30121, 30122 are poorly foliated, coarsely banded green and dull white, knotted garnet-chlorite quartzites containing about 10% garnet and 15% chlorite (pro-chlorite)

and accessory muscovite. The garnet (0.8 m.m. diam.) is partially or wholly pseudomorphed by limonite. Chlorite is primary and occurs in ragged stumpy laths (0.8 m.m. dimensionally oriented parallel to the foliation.

The lower portion of the quartzite at Raglan Bluff is a hematite quartzite containing from 5% to 50% hematite. The limonite has replaced garnet and also quartz along the inter-granular contacts. Small patches of sericite probably represent also sericite alteration of quartz.

(c) "Fincham Quartzite" -

Rocks of the Fincham Group were differentiated from the Franklin Group by McLeod (1955) because the rocks are more quartzose, and of a lower metamorphic grade. At Mt. Fincham and Engineer Range this group consists of fine grained massive quartzites, schistose quartzites, and blue phyllites. Current bedding and ripple marks are still preserved in the massive quartzites. Specimen 6843 is a reddish quartzite collected by McLeod. It contains about 15% sericite which is interstitial with respect to the quartz grains, a few small flakes of muscovite 0.05 m.m. long, accessory brown-green tourmaline and small irregular bodies of limonite. The limonite produces a banding which defines the folded surface. The quartzite is uniformly fine-grained, with an average grain size of 0.1 m.m. Foliation in thin section is lacking and lineation in the

hand specimen is very feeble.

The schists in hand specimen are similar in appearance to the glossy blue phyllites of the Governor River Phyllites. In thin section, however, (6767, 6769) they are seen to be much finer-grained and devoid of garnet, biotite and albite.

The "Fincham Group" in the Raglan Range area is mainly schistose quartzite with thin bands of quartz-muscovite schist. Quartzites are usually well foliated, the foliation being parallel to the compositional banding. Lineation is well developed; the same types as are found in the quartzite on the Raglan Range.

The quartzite is mainly dirty white and red-brown in colour, with occasional purple and green tints. Small round pits are common on weathered surfaces, very similar to those in the quartzite to the east, from which garnet has weathered. On freshly-cut surfaces this feature is expressed as brown-green spots of limonite averaging 1 m.m. in diameter, e.g. Spec. 30123. Pearly white quartzite is also present, and quite common at the northern end of the slab where it is separated from the overlying Palaeozoic rocks by up to 200' of quartz-muscovite schist. These are fine-grained, saccharoidal, with thin sheaths of pale green muscovite-rich layers.

Specimen 30213 contains dominantly quartz with

an estimated 5% limonite and 3% sericite. The majority of the quartz grains form a mosaic of interlocking, elongate grains averaging 0.5 m.m. long and ranging up to 2 m.m. long. Grains as small as 0.05 m.m. are present and occur along the borders of the larger grains. Grain boundaries are iron-stained, irregular but not sutured. Wavy extinction is common and the elongation index of grains may be as much as 7 to 1. Limonite occurs in two forms. Laths with jagged edges occur up to 1 m.m. long lying parallel to the foliation and spotted to varying degrees with sericite. The form is very similar to that of muscovite. Muscovite has altered to sericite which has then altered to limonite. Limonite also occurs as round lumps up to 1 m.m. diameter, included with quartz and sericite. The schistosity bows around the pseudomorphs. These were originally garnets.

Specimen 30124 is a pearly-white quartzite from (813500 yN, 372000 yE.). It contains clear quartz, and fresh muscovite averaging 0.5 m.m. long. A feature of this slide is the abundance of planes of liquid inclusions. The lines are more or less straight and sub-parallel but occasionally intersect at angles as high as 20° .

In both these quartzites the foliation is defined by the preferred dimensional orientation of quartz, aided by the parallelism of muscovite flakes.

The interlayered schists are green and brown banded and slightly lustrous. Slide 30125 is fine-grained and porphyroblastic. The ground mass consists of quartz and yellow iron stained muscovite flakes up to 0.2 m.m. long. The porphyroblast range in size from 0.5 m.m. to 3 m.m. diam. consisting of a core of yellowish sericite and a rim of dirty brown chlorite. The presence of rectangular cracks, included quartz granules and the porphyroblastic habit indicate that these are pseudomorphs of garnet.

Chemical analysis of this schist is given on Table 2.

Mineralogically the quartzite and schist resemble the garnet muscovite rocks further to the east and differ markedly from the true Fincham Group rocks. The chemical composition of specimen ³⁰¹²⁵ is compared with the Franklin Group schists on the A.C.F. diagram, Fig. 3. It plots in the same area, the falls into the same metamorphic facies as the Franklin schists.

Texturally, the quartzites and schist differ only by the smaller-grain size. The petrology of these rocks indicates that they belong to the Franklin Group, an idea supported by structural evidence.

(d) Finer-grained quartzites and schists -

Fine-grained varieties occur in isolated patches within the upper Franklin Group, and are also associated with the gradational nature of the upper contact of the Governor River Phyllite. The isolated patches are not infolder low grade rocks, but can be seen to grade along strike into the normal coarse Franklin Group rocks.

Specimen 30126 is a dirty white to light grey banded quartzite outcropping at co-ordinates 814000 yN, 37600 yE. about 6,000 feet (tectonically) above the contact with the Governor River Phyllite. Everywhere on the outcrop are visible small dragfolds (2.4 c.m.s. across). Its constituents are mainly quartz and muscovite, with garnet, albite, chlorite, tourmaline, rutile accounting for only 5%. Texturally, it is very similar to the Mary Group quartzites, since the quartz grains are non interlocking are not normally in contact with each other, being separated by small muscovite flakes (0.06 m.m. long). The banding is due to variations in grain size of quartz (0.03 m.m. to 0.1 m.m. diam.) and to variations in the muscovite content. The muscovite is generally dimensionally orientated in the axial surface of the folds. Similar fine-grained schists are found at co-ordinates 813500 yN, 378500 yE.

The bed of quartzite lying closely above the Governor River Phyllite at its western extremity grades

south-westward along strike into rocks more like the Fincham Quartzite from Mt. Fincham. Specimen 30127 from co-ordinates 810000 yN, 375500 yE is 400 yards south-west of specimen 30117 which contains kyanite and has already been described, (page 34). It is a clean glossy white saccharoidal quartzite. The coarser bands are distinctly granular. What appears to be cross-bedding (Plate VIIIa) is common at this locality. The sense of overturning is not constant from the outcrops, this being consistent with the recumbent isoclinal folds seen on all scales. Foliation and lineation are only feebly developed. In thin section it does not resemble even the finer-grained quartzites. The quartz grains are generally rounded, non-interlocking and showing incipient granulation. The muscovite is unusually small (0.05 - 0.1 mm.) compared to the quartz grains (0.7 m.m.) It is S1 muscovite defining the foliation (Page 90) and wraps around the quartz grains resembling porphyroblastic texture. The quartz grains are thus pre S1 and probably original clastic grains.

Specimen 30128 co-ordinates 379000 yE, 812000 yN. from within the schists 1500 feet above the contact with the Governor River. Phyllite is an unusual rock. In the hand specimen it resembles the finely banded quartzites of the lower grade rocks below. In thin section it is granulose, consisting of alternating layers of albite-rich material and

and granoblastic quartz-albite material. Biotite accounts for about 5%. Slide 30129 is similar but contains about 70% albite. Quartz about 25% is interlocked with, included in, or interstitial with respect to the albite. Chlorite forms 10% of the rock.

(e) Amphibolites and associated schists -

Amphibolite constitutes less than 1% of the rocks of the Franklin Group. It occurs in small, isolated and rounded bodies (Plate IV e) one to five feet in diameter, and also as tabular masses about 10 feet long, parallel to the foliation in the containing schists. The rounded bodies are always coated by a veneer of milky quartz. Generally, the tabular amphibolite, in hand specimen, is fine-grained, dark green with light pink garnet porphyroblasts 1-3 m.m. diam. Foliation is distinct but there is usually no lineation. Coarse-grained massive amphibolite appears to be typical of the boudin bodies.

Specimen 30130 is a fine-layered, foliated amphibolite consisting of: -

Amphibole	50%
Garnet	21%
Quartz	11%
Sphene	8%
Ilmenite	5%
Apatite	2%
Plagioclase	2%
Biotite	1%

It has a schistose texture but without any segregation, the

schistosity being due to parallel alignment of elongate sub-idiomorphic to xenomorphic prisms of amphibole (av. length 1.0 m.m.) Some of the amphibole is in the form of short interlocking prisms. The slide is peppered with equidimensional xenomorphic garnet which form small knots in the foliation. Inclusions, mainly of quartz apatite and sphene do not have any orderly arrangement. The garnet is fractured and slightly disaggregated. Quartz is interstitial, and also occurs as a coating around the garnet porphyroblasts. Small quantities of biotite occur in small (0.1 m.m.) sub-idiomorphic flakes, cross-cutting the amphibole. Elongate aggregates of minute grains of ^{sphene}sp~~here~~ are oriented parallel to the schistosity thus giving the slide a streaky appearance. Sphene is unusually common.

A similar foliated amphibolite (30131) contains altered muscovite and quartz. The muscovite occurs in fine flakes forming elongate aggregates which were once either plagioclase or earlier muscovite. Garnet is "snow-balled".

Typical of the massive unbanded amphibolites is specimen 30132, the mode of which is :-

Amphibole	64%
Garnet	20%
Quartz	8%
Biotite	2%
Ilmenite	4%
Sphene	1%
Apatite	1%

Actinolite occurs in xenoblastic and poikiloblastic broad interlocking prisms 3 m.m. long. The crystals tend to be slightly fibrous. The inclusions are quartz, garnet and sphene and also colourless, vermicular and minute globular inclusions are present, occurring in wavy parallel lines usually following a crystallographic direction. These are either an exolved mineral or liquid inclusion cavities. Garnet is xenomorphic, equidimensional and small (1 m.m.) It is cut by fairly regular rectangular cracks and often fragmented, the fragments being pushed apart by quartz and amphibole. The amphibole itself is bent and splintered. Biotite is sub-idioblastic giving no indication of having been sheared.

(f) Knotted amphibole schist and biotite schist -

At co-ordinates 376500 yE, 812500 yN. in a creek bed are exposed small tabular and spherical amphibolite masses and unusual schists bearing amphibole and biotite. The schist occur in layers up to 10 feet thick, interlayered with normal quartz muscovite schists. A knotted amphibole schist (30132) is a mottled blackish green and light pink rock with large (10 m.m. ave.) metacrysts of green amphibole oriented with a prism face in the foliation. A chemical analysis of this rock is given on Table 2. A point count gave a mode :-

Albite	27%
Amphibole	15%
Biotite	22%
Quartz	21%
Zoisite	13%
Sphene	1.5%
Apatite	1%
Ilmenite	0.5%

The rock consists of porphyroblastic amphibole comprising 14% of the slide in a background of abundant small (1.5 m.m.) porphyroblastic albites with biotite, quartz and zoisite. The amphibole is a pale green hornblende occurring in sub-idiomorphic crystals with an elongation ratio of 5:1. It is poikilitically included with zoisite, quartz and occasional biotite, the inclusions tending to be arranged in lines parallel to the length (C-axis) .

The background has a schistose texture, since albite is wrapped by trails of biotite and zoisite which define the foliation. Inclusions of quartz, biotite and amphibole fragments are arranged in straight lines and gentle curves. The inclusions commonly amount to 30% by volume of the albite and it is difficult to distinguish between ground mass and albite. In some of the albite crystals in slide 30132 (Plate VII i) two internal S-surfaces are demonstrated by :-

- (i) Trails of basal sections and needles of zoisite
- (ii) Lines of quartz granules and elongate flakes of biotite, inclined at a large angle to type (i).

This is the only example in which two Si in albite have been observed.

Thin discontinuous lines of biotite, fragments of amphibole (which are often surrounded by an interlocking mosaic of quartz) and minute needles of zoisite form the ground mass. The biotite is dichroic (red-brown to colourless) and occurs in short sub-idioblastic interlocking flakes. Spene occurs as aggregates of small irregular grains scattered sporadically throughout the rock.

Occurring at the same locality are biotite-albite schists which appear to grade into knotted amphibole schist. These are petrographically similar, being almost identical to the albite and ground mass portion of the knotted amphibole schist. It differs in that it lacks amphibole, contains very little zoisite and contains muscovite (30134), Biotite schists in which the place of muscovite is taken by biotite occur only at this locality and so appears to be genetically related to the amphibolites.

A specimen (30133) of a fine-grained micaceous quartzite from the wall rock from a body of massive amphibolite is a dirty-grey-black colour whereas 10 feet away it is a normal muscovite quartzite. Although this specimen is probably not the exact original wall rock of the amphibolite, since all lithological contacts are modified by tectonism, in thin section it shows evidence of biotitisation.

It contains :

quartz	53%
biotite	30%
muscovite	5%
albite	11%
kyanite	1%

few?
The biotite occurs in dichroic green, ragged flakes replacing muscovite and also as new crystals.

The significance of the kyanite here is not known.

There is thus petrographic and field evidence to suggest that the biotite in the biotite-rich rocks is derived from the amphibolites. It is seen on page 3 that this biotitisation is probably the result of a redistribution of iron and/or magnesium at a time after the emplacement of the amphibolite.

METAMORPHISM

Chemical Analyses:

A total of eight chemical analyses of Franklin Group rocks were kindly carried out by the Department of Mines, including one of the Governor River Phyllite, five Franklin Group schists, one massive amphibolite, and one knotted amphibole schist, these are presented in Table 2.

Explanation of Table:

7. Specimen ³⁰¹⁴⁹~~82~~. Coarse grained garnet-albite-muscovite-schist from beneath quartzite at Raglan Bluff.
8. Specimen ³⁰¹⁰⁸~~85~~. Governor River Phyllite from Joyce Creek. Contains albite, muscovite and no garnet.
9. Specimen 6275. Garnet-albite schist collected by A.H. Spry from Raglan Range.
10. Specimen ³⁰¹¹⁴~~1~~. quartz-muscovite-albite-garnet schist from near old timber mill.
11. Specimen ³⁰¹²⁵~~A26~~ chloritised garnet muscovite schist from thin band within "Fincham Quartzite".
12. Specimen ³⁰¹⁵⁰~~A44~~ quartz-muscovite-chlo^vite schist from coordinates (813500 yards N, 372000 yards E), lying above "Fincham Quartzite".
13. Specimen ³⁰¹¹⁵~~40~~ Biotite chlo^vite, knotted albite schist from coordinates (377500 yards E, 814000 yards N.). In creek bed 3,000 feet north west of Timber mill.

TABLE 2

	7	8	9	10	11	12	13
SiO ₂	68.00	68.46	69.28	67.2	73.70	71.60	49.92.
Al ₂ O ₃	17.00	15.72	15.64	17.67	11.62	14.72	16.76
Fe ₂ O ₃	1.96	0.92	0.57	2.30	2.95	1.04	4.21
FeO	2.54	3.02	4.61	2.72	3.69	2.62	8.84
MnO	0.02	0.02	-	0.02	0.04	0.02	0.05
TiO ₂	0.69	0.76	0.45	0.94	0.45	0.69	2.44
P ₂ O ₅	0.06	0.06	-	0.40	0.03	0.05	0.24
CaO	0.60	0.32	0.68	0.32	0.04	0.16	0.72
MgO	1.16	1.43	1.48	1.19	2.00	2.56	6.91
Na ₂ O	1.31	1.18	1.93	0.98	0.09	0.71	2.12
K ₂ O	3.64	3.64	3.42	3.47	2.47	3.02	1.61
H ₂ O-	0.19	0.12	0.10	0.18	0.36	0.14	0.53
H ₂ O+	2.93	2.79	1.96	3.06	2.96	2.94	5.33
FeS ₂	-	1.29	-	-	-	-	-
SO ₃	-	0.14	-	-	-	-	-
	100.00			Garnet 6.6 quartz 39.8 muscovite 46.5 albite 6.3 iron ores 1.0 tourmaline 0.3		Garnet 0.4 quartz 5.32 muscovite 38.0 albite 2.6 chlorite 4.8 apatite 0.3 tourmaline 0.6 sphene 0.1	quartz 22.4 albite 44.0 biotite 19.6 chlorite 13.0 iron ores 1.6 sphene 0.2 apatite 0.2

TABLE 2

	14	15	16
SiO ₂	44.78	58.18	58.10
Al ₂ O ₃	13.44	15.36	15.4
Fe ₂ O ₃	2.41	0.79	4.0
FeO	16.22	5.31	2.5
MnO	0.36	0.09	-
TiO ₂	2.81	0.61	0.7
P ₂ O ₅	0.40	0.15	0.17
CaO	9.12	5.00	3.11
MgO	7.01	6.72	2.4
Na ₂ O	1.65	1.69	1.30
K ₂ O	0.47	2.95	3.2
H ₂ O-	0.07	0.49	8.0 {accessories + water
H ₂ O+	1.58	2.61	
FeS ₂	-		
SO ₃	-		
		amph. 60.0 64.4	alb. 27.7
		gnt. 20.3	amph. 14.9
		qtz 7.7	biot. 21.8
		ilmen. 3.6	qtz. 21.4
		sphene. 1.5	zois. 12.76
		apat. 1.0	sph. 1.7
		biot* 1.5	apat. 0.9
			ilmen. 0.5.

14. Specimen ³⁰¹³² ~~18~~ garnet amphibolite, coordinates (378500 yards E, 812000 yards N).
15. Specimen ³⁰¹³² ~~27~~, knotted amphibole schist with biotite, Coordinates (376500 Yards E, 813000 yards N).
16. Average composition of shale (after Clark) Pettijohn (1957). Sedimentary Rocks, page 106.
Nos. 7, 8, 10, 11, 12, 13, 14, 15,
Analyst W. St. C. Manson.

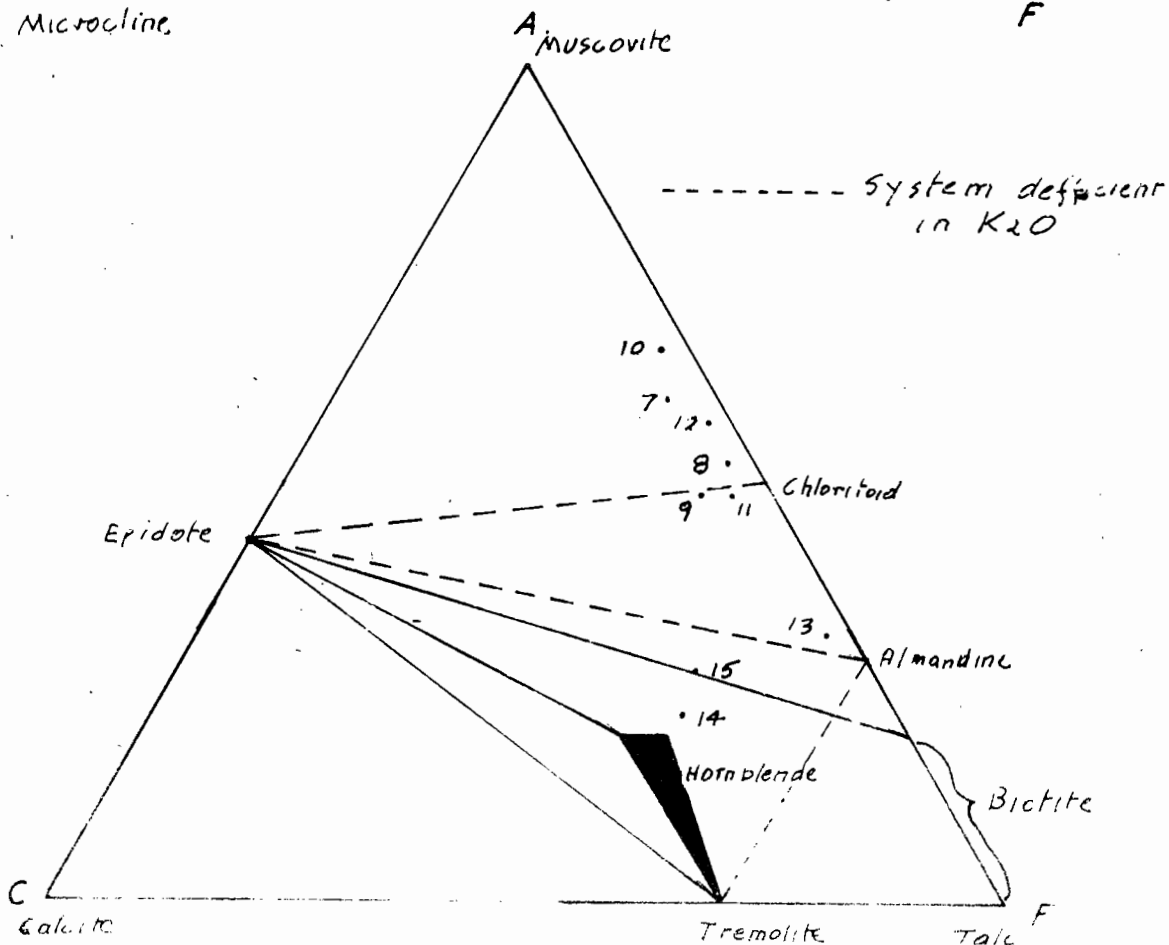
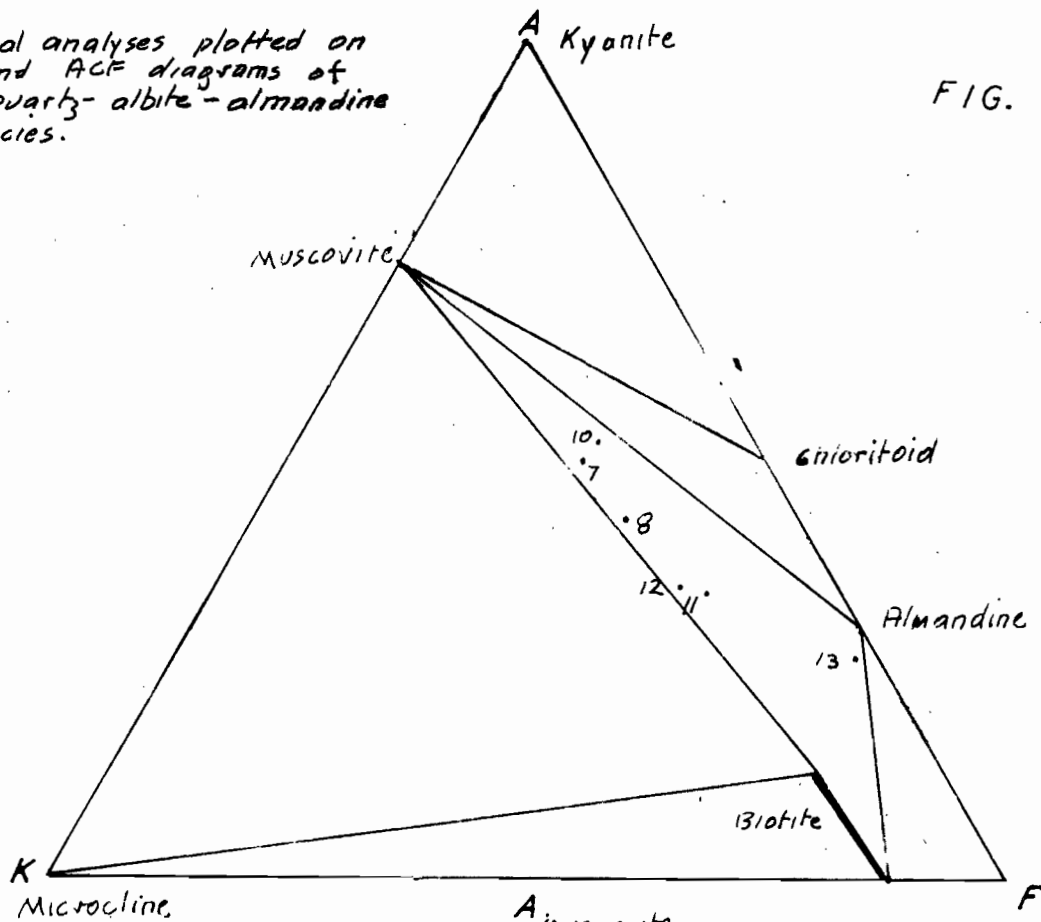
METAMORPHIC FACIES.

The Franklin Group schists and quartzites are derived by the regional metamorphism of pelitic and psammitic sedimentary rocks. Most of the schists have reached almandine grade, and although minor amounts of kyanite were found, it is not possible to delineate a kyanite zone.

The equilibrium assemblage of almandine, muscovite, biotite, and ~~in~~ kyanite in places, indicates an affinity to the quartz-albite-almandine subfacies of the green schist facies. Fig (3) are ACF and AKF diagrams for this sub-facies upon which are plotted the poles of the analysed schists. The poles all fall in the field muscovite-almandine-biotite on the AKF diagram. There is a spread towards the (FeO + MgO) pole. The cluster is also apparent on the ACF diagram. All the points fall within the biotite-epidote-muscovite-chloritoid-almandine ~~zone~~ field for a system rich in potash but epidote and chloritoid are absent. The extreme

Chemical analyses plotted on
AKF and ACF diagrams of
the quartz-albite-almandine
subfacies.

FIG. 3



deficiency of CaO is obvious, and what CaO is present is in the form of albite.

However specimens ^{30150 30115} ~~444~~, ~~40~~, contain chlorite in juxtaposition with garnet at varying stages of alteration. Normally the place of iron-rich chlorites, characteristic of the lower green schist facies is taken by almandine in the upper green schist and higher facies. However, Yoder (1952) has experimentally demonstrated that in a silica deficient environment, magnesian chlorites are stable at temperatures exceeding those assigned to the green schist facies, and can thus coexist with almandine. The chemical nature of the chlorite is not known, however, the magnesia content of the chlorite bearing schist (30115) is very high and comparable with that of the amphibolites.

The association of almandine and chlorite, which is common on the Raglan Range, is a suggestion but no positive indication of dis-equilibrium.

Evidence of apparent dis-equilibrium is not lacking, since the coexisting pairs kyanite-chlorite, kyanite-biotite, hornblende-muscovite can be found.

In order to explain these anomalous assemblages an advanced summary will be given ^{of the conclusions drawn} from petrographic and petrofabric evidence. The time of crystallization of the minerals in the Franklin Group can be related to two phases of tectonism. The earlier deformation was accompanied by syn-tectonic crystallization of biotite, garnet, kyanite, muscovite and amphibole. The second period of metamorphism, during which muscovite and chlorite

crystallized, is mainly post tectonic to the second stage of deformation. The earlier metamorphism was the more intense and so the Franklin schists are polyfacial.

The earlier metamorphism reached quartz-albite-almandine sub facies, and the later metamorphism was quartz-albite-muscovite-chlorite sub facies. Both sub facies are of the green schist facies.

Origin of Albite Porphyroblasts:

Porphyroblasts of albite are ubiquitous in the schists, and in places they were noted to be as large as 1 cm, and occupy about 70% by volume of the rock. The albite schists of the Franklin Group show a striking petrographic resemblance to those in the Caledonides of the Scottish Highlands. There has been much discussion as to whether these schists are derived from a sediment rich in soda, for example a graywacke, or whether they result from the soda metasomatism of normal pelitic sediments.

Specimens ³⁰¹⁵⁰(~~444~~) and ³⁰¹²⁵(~~628~~) are coarse quartz muscovite schists without albite and contain 0.71% and 0.09% Na₂O respectively. Specimen ³⁰¹¹⁵(~~40~~) with 44% albite contains 2.12% Na₂O, and is higher than the Na₂O content of the average shale (Table 2 No 16). Albite does not appear to be restricted to any one slab of schist, and variations in the amount of albite porphyroblasts occur along the strike of the foliation. This is slender evidence that the albite is metasomatic, but more definite evidence of soda metasomatism is given on Page (119).

Petrogenesis of the Amphibolites.

The chemical analyses of a massive amphibolite, and a knotted amphibole schist are expressed on the ACT diagram in Fig (3). That the amphibolites belong to this facies is indicated by its association with schists of the same facies, and the presence of zoisite. The amphibole rocks fall within the hornblende-zoisite (in place of epidote) - almandine-biotite field of the basic assemblage, of the upper green schist facies, deficient in potash.

Field relations of the amphibolite bodies are not sufficiently clear to designate them as ortho- or para-amphibolites. Spry (1957A) mentions intrusive amphibolites near the Franklin River which are probably ortho-amphibolite. ^{amphibolites would develop by} It seems unlikely that the lime-magnesia metasomatism of the pelitic Franklin Schists which contain on the average 0.5% CaO.

The norm calculated from analysis No 14 is :-

<u>Full Norm</u>		<u>Shortened Norm.</u>	
or	2.78%	orthoclase	2.8%
ad	14.15%	labradovite	41.7%
an	27.52%	clinopyroxene	12.3%
wo	6.25%	Orthopyroxene	22.7%
en	12.4%	olivine	8.9%
fs	16.37%	magnetite	3.5%
fo	16.37%	ilmeneite	5.3%
fa	5.30%	apatite	1.0%
mt	3.48%		
ie	5.32%		
ap	1.01%		

The shortened norm is in excellent agreement with a typical olivine basalt, with perhaps a slightly high FeO content. Further features which favour a ortho-amphibolite is the poikiloblastic amphibole, and the 5% of ilmenite.

MESOSCOPIC FABRIC.

In this paper, the terms microscopic, mesoscopic and macroscopic accord with usage of Weiss and McIntyre (1957) namely:-

- i. microscopic: the field of a thin section.
- ii. mesoscopic: the field ranging in size from a single hand specimen to a single continuous exposure.
- iii. macroscopic: the field of any size containing discontinuously observable structures, thus including major structures.

Mesoscopic structures can be divided into two categories.

Firstly those which are related to the movements that produce the regional lineation and so belong to the Precambrian orogeny. Secondly, those which deform the lineation and are thus the younger.

A. PRECAMBRIAN STRUCTURES:

1. Surfaces:

Rocks of the Franklin Group are ^h_λ characterized by two types of foliation. Foliation is used, synonymous with schistosity, to include those microscopically and mesoscopically conspicuous parallel fabrics of metamorphic origin.

Two mesoscopic surfaces are perceptible in the schists. The older of the two is the folded surface which is defined by compositional and colour banding on a scale ranging between a few m/m. to several c/m. From a microscopic study it can be shown that this is parallel to an older tectonic surface. The dominant foliation is parallel or sub-parallel to the axial surfaces of the folds in the older surface (~~See~~ Plate III) and can be seen to be the result of the parallel arrangement of large muscovite flakes.

A. PRECAMBRIAN STRUCTURES:

1. Surfaces: (cont.)

Foliation in the quartzite is a different type, being parallel to the folded surface which is likewise defined by the lithological banding (plate III). The foliation is a plane of parting due to the planar arrangement of muscovite. Quartzites lacking muscovite have no mesoscopically visible foliation. Thinly fissile quartzite is due either to large flakes of muscovite (1 c.m. long), or to fine compositional banding. This foliation has all the attributes of bedding schistosity described by Sander (in Turner 1948). Assuming the folded surface in the quartzite is equivalent to the folded surface in the schist which is not bedding, then the foliation in the quartzite is not a bedding schistosity.

Folds in the quartzite are isoclinal with straight parallel limbs, so it follows that the foliation will mostly be planar, but curved at the hinges of the fold. The orientation will not be constant in any one exposure, however there will be a statistically greater proportion lying parallel to the axial surfaces of the folds.

In the majority of cases, the quartzites have only this "bedding schistosity". However, in some quartzites, a sub-ordinate foliation which is axial surface with respect to the folded surface is developed as well as the "bedding schistosity" (Plate III e).

2. Linear Structures:

Linear structures are ubiquitous, the following types are present:-

(a) a parallelism of lines on the foliation surface of quartzites giving a fine rectilinear streaming. It is manifest by fine striations and small steps on the foliation surface, and the dimensional orientation of aggregates of quartz grains and single large muscovite flakes. This is the most common type found in quartzite and is not found in schist.

2. Linear Structures (cont.)

(a) This is the type termed Streimung by Sander (Turner and Verhoogen P.534)

(b) Mullions: Fold mullions are common in the cores of the larger recumbent folds in quartzite. In any one outcrop the Mullion axes are mutually parallel, and parallel to the fine streaming and parallel to the axis^s of the recumbent fold. These are cylindroidal undulations of the bedding? having radii of curvature from a few c.m.s to 40 c.m.s). The style of these mullions is illustrated Plate II ab.

These mullions are not detached from the fold and so differ slightly from those at Oyckell Bridge (Scotland), described by Wilson (1953). The long axis is an axis of rotation and normal to it is a plane of (monoclinic) symmetry. The lineation is a B-lineation.

Another type of mullion found in quartzite is formed by the splitting of the rock along surfaces parallel to the banding, and along irregular surfaces which are either sub-parallel to the axial surfaces of the recumbent fold, or which intersect with the banding parallel to the lineation. These mullions are elongate rock prisms, and in cross section are flattened, tending to be rounded or rhombic (Plate II c)

(c) Minor Fold Axes: The axes of small folds appear to be parallel to the streaming lineation, and also parallel to the larger fold axes. In many of the micaceous quartzites, the folded surface is tightly crumpled into miniature chevron and isoclinal folds. Consequently, the folia of muscovite impart to the rock a fibrous rather than a platy appearance.

Linear Structures (cont.)

(d) Quartz Rods: In the cores of folds are commonly found slender rods and prisms of quartz, several feet long, and elongated in the direction of the lineation (Plate II d). In cross section they are lenticular or roughly equi-dimensional. The quartz rods in Plate II ef (172), in end view are recognisable as remnants of quartz veins that have been folded along with the foliation. The surfaces of the rods are often marked by striations parallel to their axes.

(e) Intersection of Surfaces: Linear structures in the schists are mainly due to the intersection of the dominant foliation and the folded surface. The schists split along the dominant foliation revealing a parallel colour banding. This type can also be found in the quartzites where it splits along the same type of fractures that produce the irregular mullions.

B. MINOR FOLDS:

Minor folds are exceedingly abundant, and scarcely an outcrop can be visited without observing folds. They vary in height and width from less than 1 cm. up to the macroscopic size. Folding in the schists is different in style to the folding in quartzite.

Plate III a,b,c,d,e,f, illustrates typical profiles of folds in quartzite. These folds are characterised by the presence of a "bedding schistosity" and by the absence or perhaps the embryonic development of a discrete surface in the axial surface. In many cases (Fig. 1) the lithological banding retains its orthogonal thickness as it curves around the crest of the fold and much of the movement during folding superficially appears to have taken place by slip along the foliation plane. The common style of folding in the quartzites appears to be attenuation in the limbs, but with ~~one~~ banding at the crest retaining its orthogonal thickness. The banding in the cores of the folds is intensely contorted forming ptygmatic-like, zig-zag and z-folds

which are recumbent and mostly isoclinal.

Widely-spaced approximately planar fractures which are sub-parallel to the axial surfaces are commonly associated with these folds.

Folds in the schists are generally smaller, but there are more of them to the outcrop. The folds illustrated in Plate IV a.b have a typically similar style. Points of inflection of the folded surface persist for distances of many feet along the schistosity, and the limbs are attenuated. Deformation in the schist appears to have taken place by slip on parallel and sub-parallel slip planes.

In all exposures of mesoscopic folds, the linear structures appear to be parallel to the axis of the fold. For two folds β -diagrams were constructed from foliation measurements around the fold crests. In both cases the β -maxima coincided with the lineation maxima. Therefore, the tentative proposal is that the linear structures are closely parallel to the axis of the largest mesoscopic folds.

All folding is recumbent and mostly isoclinal. The fold axes as indicated by the linear structures throughout the area, plunge toward 300° (true) at angles varying from 0° to 50° . The foliation measurements in schists will represent the orientation of the axial surfaces of the folds. In the quartzite, by virtue of the style of folding, the attitude of the axial surfaces will be represented by the statistical maximum of foliation measurements in an area of about one square mile. The axial surfaces of all folds, as deduced from the foliation measurements on the map, dip westerly or north westerly at angles ranging from almost horizontal up to 60° .

4. Boudinage:

These structures are best developed in the pre-tectonic quartz veins when injected into schists, (Plate IV d). Boudins are found in all positions on the folds although more frequently in the core region where all stages between pinch and swell structures and discrete quartz rods are obvious. The length of the boudins is not known. In all cases, the boudin axis is parallel to the lineation in the enclosing rock. The surface of the boudin itself is often striated parallel to the axis.

The amphibolite bodies constitute another type of boudin. Their exact shape is not known since they are exposed only in a section normal to the lineation. In this plane they are seen to be circular (Plate IV e).

Mesoscopic Symmetry:

On a mesoscopic scale the fabric is characterised by a lineation, and an axis of rotation normal to a plane of symmetry. Mullions, quartz rods and minor folds all have a plane of symmetry normal to their respective axis. The lineation is by definition (Sander 1950, in Wiess 1954 page 11.) B-lineation. The symmetry is strongly monoclinic suggesting monoclinic movement in a direction normal to the lineation.

B. LATER MINOR STRUCTURES:

1. Joints:

Little time was spent examining joints since the measurements of joints is very time consuming. The most common type of joint observed is that normal, or approximately normal to the lineation, in quartzite. These generally assume two forms. Firstly, small openings varying from about 1 cm. to 30 cms. long, seen on foliation surfaces to be spindle

to lensoid shaped. These often have raised lips and are filled with coarse vein quartz giving an appearance of welts on the foliation surface (Plate V a). These joints are responsible for the development of another type of pinch and swell structure. In a thin alternation of quartzite and quartz schist, the raised edges of the joint in quartzite causes the schist band to constrict. These are different to the boudins described earlier because the pinched body is the incompetent body, and the axis is about normal to the lineation.

The second type is fairly regularly spaced clean fractures cutting straight across one outcrop. These are not usually filled with quartz but a thin veneer of vein quartz on adjacent joint faces is common. Plate 11 b illustrates these joints.

Joints of this type are common phenomena of the crystalline basement throughout the world and have been termed cross joints or a.c. joints since they are about parallel to the a-c. fabric plane. Fig 5. is a histogram of 80 measurements representing the angle between the direction of plunge of the lineation and the trend of the joint, measured in the foliation plane. The majority of the cross joints are inclined at 83° to the lineation and so are not true a-c joints. The cross joints almost invariably intersect with the a.c. fabric plane parallel to c, that is, are normal to the foliation plane.

The cross joints show the characteristics of tension jointing, due to elongation in a direction about parallel to the fold axes. They are clearly later than the folding since the lineation is bent up at the lips and the quartz crystals are sub-hedral or euhedral.

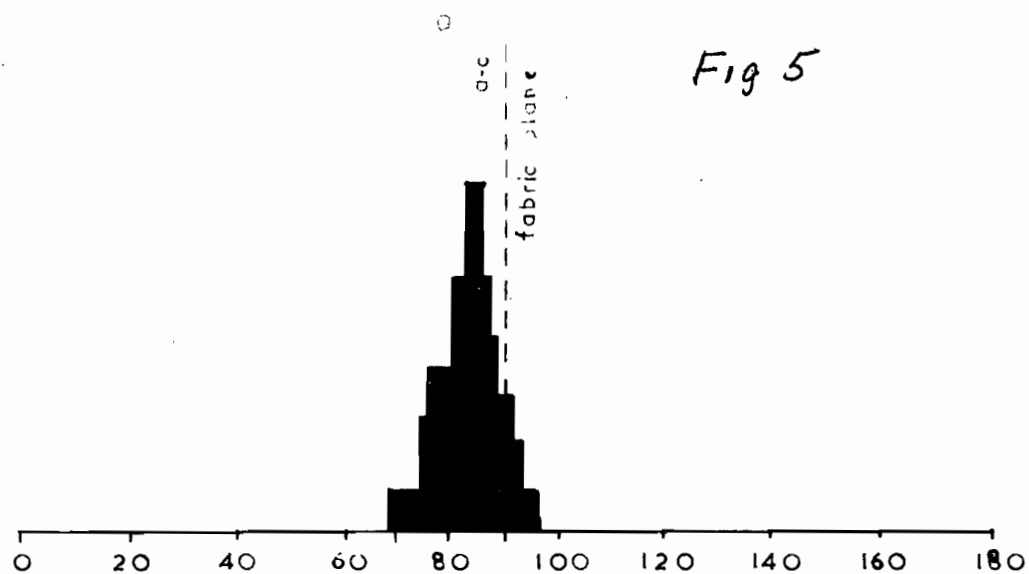
The second most common type of joint in quartzite ^{is} ~~are these~~ ~~that~~ which intersect with the folded surface parallel to the lineation. These may be parallel to the axial surface of the fold or inclined to the axial surface.

Another type of joint exist in pairs which intersect in a line normal to the foliation and are symmetrically disposed about the lineation. Many other joints are present which have no constant orientation with respect to the lineation and foliation.

Two possibilities as to the age of the cross-joints must be considered:-

(a) The joints are clearly later than the Precambrian folding and may belong to a distinctly later orogeny. In this case the pre-existing anisotropy would, in some way control the orientation of the joints. However, the joints are earlier than some of the minor structures associated with the Tabberabberan Orogeny since they are deformed by folding and brecciation.

(b) The universally constant orientation of these joints, with respect to the foliation and lineation, in this area, and throughout the world suggests that they are genetically related to the folding. An elongation parallel to the fold axis during a later stage of the Precambrian orogeny is indicated by the nature of the joints. That elongation parallel to the fold axis has taken place during the folding movements, can be demonstrated by the dimensional elongation of quartz grains, especially in the hinge area of the fold. The best explanation that can be offered is that the cross-joints are the expression of this elongation at a stage when the temperature had fallen, accompanied by a lowering in the elastic limit of the rock. A point is reached whereby stresses, whether residual or active, active, are released by fracturing rather than by flow. Therefore, all those



*HISTOGRAM SHOWING RELATION BETWEEN
CROSS JOINTS AND DIRECTION OF LINEATION*

Later Minor Structures (cont.)

Q. cont.

joints which have a constant orientation with respect to the foliation, and lineation probably represent the movement picture of the final stage of the Precambrian orogeny.

2. Joint drags: Joint drags, named by Knoll (1951) are developed in thin zones of shearing in which the foliation is abruptly bent into miniature monoclinical folds having straight limbs and sharp inflection points. The zone varies from 1/16" to 1" in thickness and is steeply dipping or vertical. They affect both schist and quartzite and commonly the one drag joint can be traced from schist through to the quartzite. However, in some cases the joint drag in schist is seen to stop at the contact and its continuation is expressed as a micro fault.

These structures are manifest by ridges, ripples and small steps in the foliation. The amount of offset is about the same as the width of the shear band. They may be solitary or occur in swarms all having approximately the same orientation and so give the rock another lineation. Frequently, two sets occur mutually inclined at $30 - 40^\circ$ and offsetting in different directions; these may be conjugate sets.

Measurement of their orientation is difficult since the rock rarely parts along the joint drag. (Fig. (4.) is a rose diagram of the direction of 120 lineations given by the intersection of the foliation with the shear zone. The orientation of the foliation is fairly constant over the area, and the plane of the joint drag dip steeply so that this lineation is not appreciably different from their strike. All trend within the sector $285^\circ - 035^\circ$ (true). Two dominant trends are apparent, the majority lie between $010^\circ - 020^\circ$ (true). These may be two independent trends or genetically related conjugate pairs.

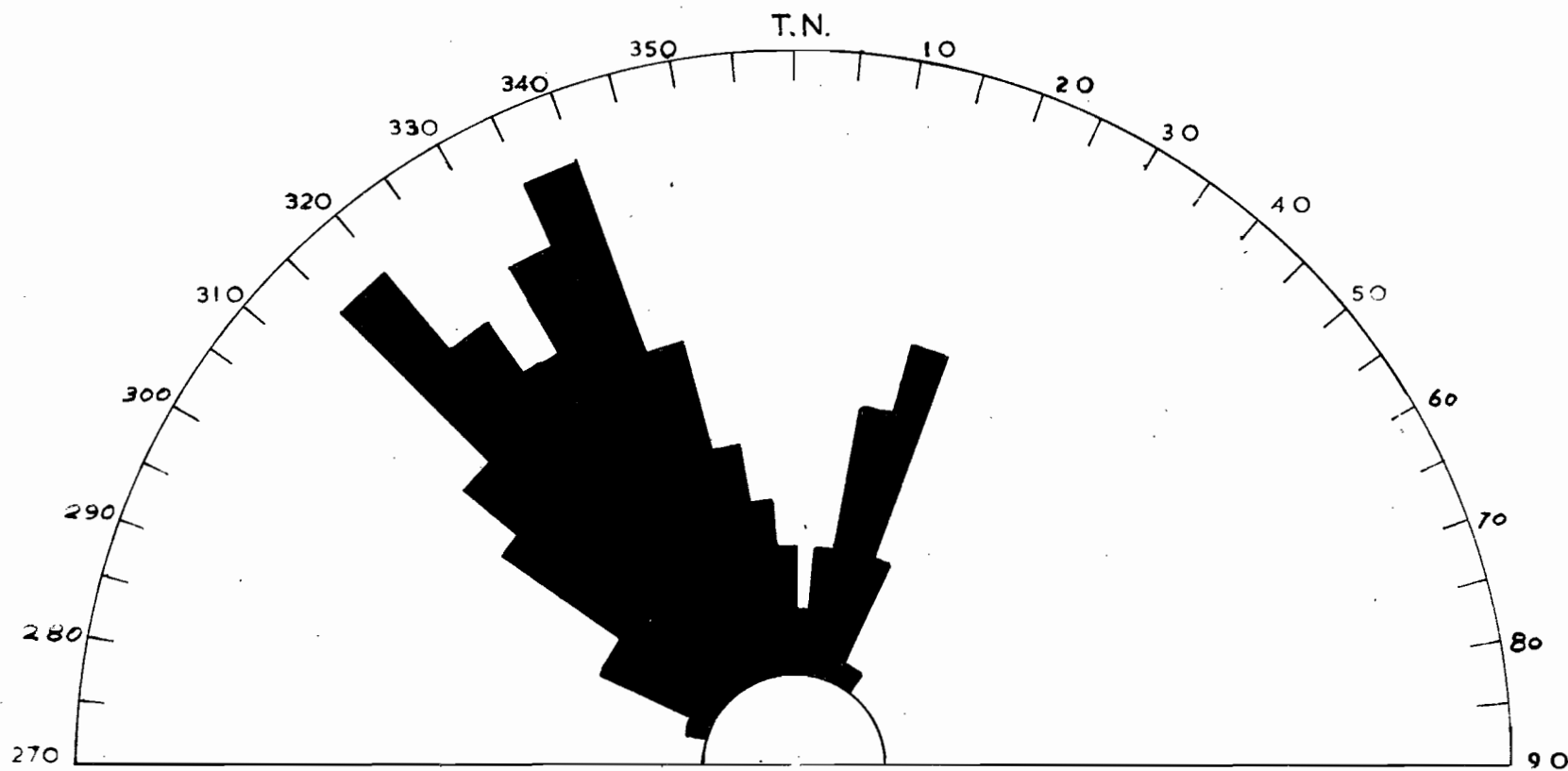


Fig. 4 Rose diagram of the trends of 120 joint drags measured in the plane of the foliation.

Joint drags are more common in two areas, the fault complex covered by sub-areas 10,14,17,20, and in the vicinity of the E.W. fault along the Governor River. The number of readings is too small to attempt any correlation of regional distribution and faulting with the dominant trends. That these structures are probably related to the phase of Tabberabberan block faulting is indicated by their close spatial association with faulted areas, and their brittle style of deformation. At Duck Creek (Spry pers.comm.) joint drags occur in the Precambrian rocks and can be traced across the contact into Tabberabberan deformed Ordovician rocks.

3. Minor Folds:

Minor folds of the later category are common in the Mary Quartzite at co-ordinates (379500 yE, 810500 yN) and on the ridge $\frac{1}{2}$ mile north east of the old timber mill. Both these localities are in the vicinity of the crest of the postulated Tabberabberan anticline (Page 73). These folds are distinguished by the fact that they refold Precambrian folds, for example Plate V b and consequently they are seen to deform the Precambrian lineation. The style is characteristically different from the Precambrian folds. There is no development of a new lineation or foliation and the deformation is a more brittle style. The fold axes generally plunge gently into the north-west quadrant, and the axial surfaces vary from sub-horizontal to vertical but do not maintain a

constant orientation in the one outcrop. The types of folds include :-

- 1.) Accordion-like folds having sharp crests and straight limbs. The folds of specimen ³⁰¹⁴¹ ~~36~~ (Plate VII, b) have an amplitude of 2 c.m. and an axial width of 6 c.m. The axial surfaces are parallel. Irregular fractures which are sub-parallel to the axial surface produce a rudimentary fracture cleavage. Because of a slight thickening of the foliation layers in the crests, and the absence of good cleavage parallel to the axial surface, the fold is not a true accordion fold.
- 2.) Asymmetrical, ripple-like folds (Plate V c). These may be genetically related to the joint-drags which they resemble, they differ in that they are larger and the inflection points are not as angular.
- 3.) Irregular crumpling of the foliation (Plate Vd) is visible on a larger scale. Regular and irregular close jointing, in some cases amounting to brecciation are a common accompaniment to this type of fold.

The age of these folds is, in all probability, Tabberabberan, with a remote possibility of some of them being related to the Jukesian Movement.

4. Small Faults:

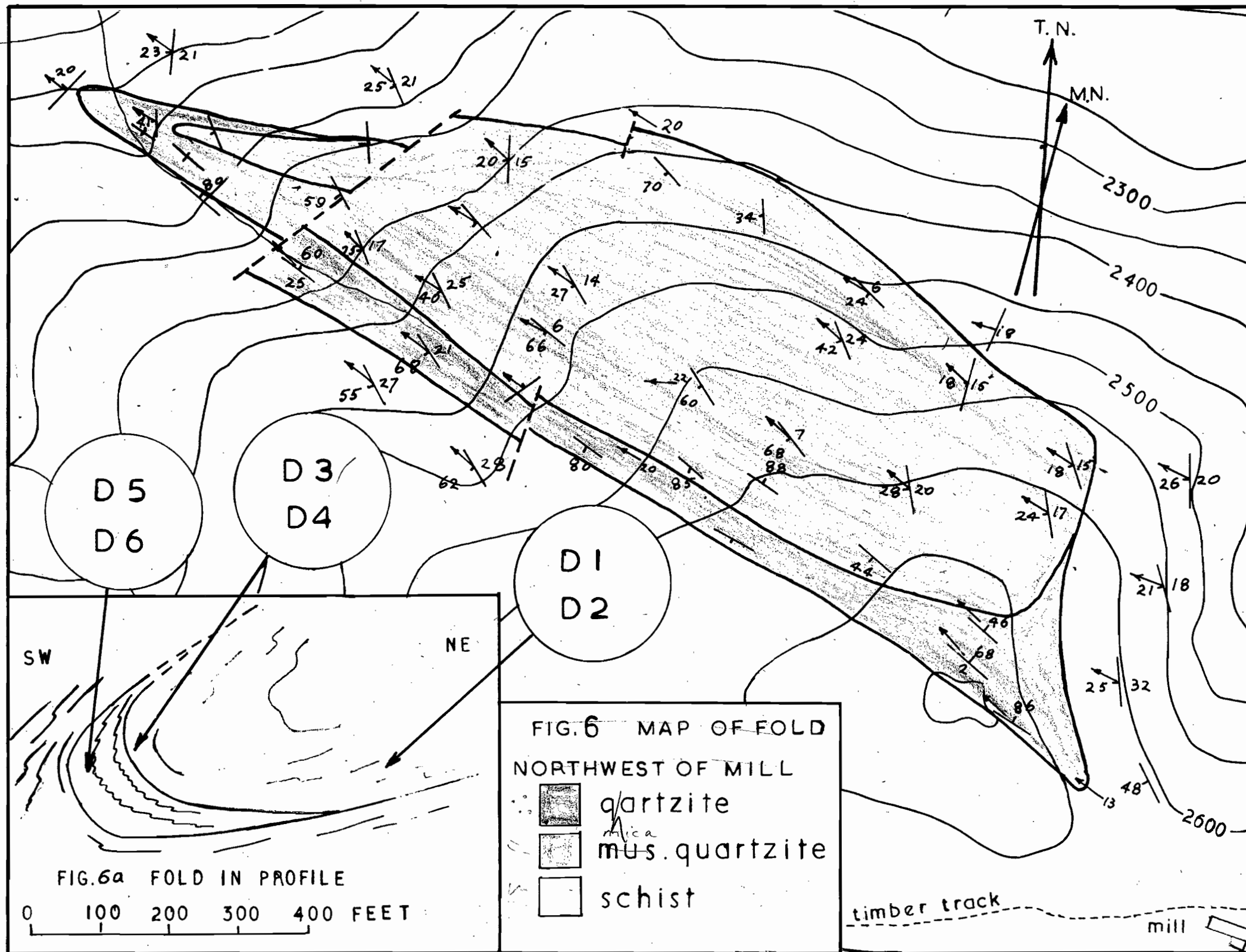
Small faults are invariably seen in all good exposures. Measurable displacement range from a fraction of a centimeter to several metres. Dragging associated with these faults accounts for some of the variations in attitude of foliation within short distances, in areas which seem to be free from the previously discussed minor folds. Within the fault zone the rocks are brecciated and silicified. Pyrite and limonite are present in places. There appears to be no relationship between the amount of displacement and the degree of brecciation. Faults can be found with only a few c.m. displacement having a brecciated zone of about 30 cm. wide. Re-working of faults, evidenced by two oblique sets of slickensides in the one fault zone may possibly explain this anomaly.

MACROSCOPIC STRUCTURE.

Mapping of the area reveals that the Raglan Range consists of slabs of quartzite and schist piled one on top of each other and dipping generally to the west. Rapid variations in thickness are common, and many of the slabs completely pinch out. Diagram D I3 is an equal area plot of foliations from the area, and shows a 12% maximum of foliation poles and a girdle ^{to} normal the lineation maxima. The two alternative structures for the whole area ^{are} ~~is~~ either a series of rock slabs each of which are internally folded, or units that have been recumbently and isoclinally folded so as to give repetition of rock types. *confused*

A common feature of the fabric in the region where a slab pinches out is the abundance of mesoscopic folds and mullions, the fibrous texture of the muscovite-quartzite and the vertical attitude of the folded surface. One such region was examined in detail in order to show that it is the crest of a major recumbent fold, and thence to relate the macroscopic, mesoscopic fabrics and later the microscopic fabric.

The area in question is a strip 2,000 feet long running north-west from the disused timber mill, and contains a lens of quartzite in garnet schist. The shape of the lens is seen from Fig. (6). The S-surfaces in the quartzite along the south-west contact with the schist dip steeply either to the north-east or south-west, whereas on the north east side they dip 20° - 30° to the north-west. The mapping was done with tape, Abney level and compass, and about 50 foliation and lineation measurements were taken, some of which are recorded on fig. (6). A profile was prepared by drawing serial sections along eight cross traverses and superimposing these by axial projection. (This method was used instead of axial projection onto a plane because of the limited topographic control and the presence of two small faults.) The structure of



MACROSCOPIC STRUCTURE (cont.)

the quartzite is seen to be a crest of a recumbent fold impressed into the side of the hill.

Between the quartzite and the schist is a layer of micaceous quartzite which is intensely crumpled, and whose orthogonal thickness decreases from 100 feet in the hinge to less than five feet on the flank. The fold, therefore, has a characteristic of similar folding. The approximate trend of the fold axis, given by a line joining the extremities of the lens, is 300° (true) and plunging 20° .

Diagram D I2 is a stereographic plot of the folded surfaces in schist and micaceous quartzite. The poles form almost a complete girdle around a great circle whose axis plunges 22° at 299° . The gap in the girdle is due to the upper limb having been mostly eroded away. The lineations form a tight cluster about this axis showing that ^{on} this scale the structure is homogenous. A few of the lineations (not included in D I2) in the close vicinity of the faults did not comply to this pattern. The symmetry is strongly monoclinic with a plane of symmetry in the plane of the profile and an axis of rotation normal to it.

Within the quartzite, the folded surface is bent to Z-folds, and S-folds, having a height up to 20 feet. These are drag folds related to the major fold and have an axis parallel to that of the major fold.

The folded surface in the micaceous quartzite is intensely crumpled into cylindroidal folds with an amplitude and wavelength of about 2 - 4 feet, and again, on a smaller scale it is crumpled into concertina folds with an amplitude and axial width of about 2 cms. (fig. —). These folds pass into asymmetrical drag folds on moving out into the limbs. In the crest, a second surface is partially developed. This is the axial surface of the small concertina folds. Five measurements of this surface are plotted as circles as on D I2. The axial plane of the major ^{fold}, as best as can be determined from the profile is

344° (true) dip 21° W. It is also plotted on D (2°) where it is seen to coincide roughly to the new surface. In the surrounding schists the dominant foliation is the axial surface schistosity. Near the quartzite, the orientation of this foliation is controlled by that of the quartzite, although further away it assumes a fairly uniform orientation.

Analysis of Foliations and Lineations:

In view of the structural complexity, an examination of the regional structure cannot be attempted from a stratigraphical approach, but rather by a statistical analysis of structural elements such as foliations, lineations and fold axes. Diagrams DI3 and DI4 respectively are equal area projections (lower hemisphere) of 600 poles to foliation surfaces and 600 lineations taken from the whole of the area.

No distinction is made between the type of lineation and the type of foliation.

The significant features of the diagrams are :-

- (a) A 25% maximum (DI4) of lineations trending 301° (true) and plunging 25°.

All the poles to the foliation lie on a wide great circle girdle.

On DI3 is drawn the great circle to the pole of the lineation maxima. This plane passes through the foliation maximum and approximately bisects the width of the girdle. The foliation maximum is 12% and is itself elongated approximately in this plane. The girdle is complete although weak at the extremities, being completed by the 0 - 2% area. The surfaces are, therefore, folded about an axis which coincides with the lineation maximum.

If only these features are considered the area would be homoaxial.

- (b) The 15% contour (DI4) begins to show two spreads which are quite pronounced by the 5% ~~xxxxxx~~ contour. The first is a spread

MACROSCOPIC STRUCTURE (cont.)

in the lineations about a near vertical axis, manifest by those lineations trending toward west, south-west, north-west and northeast. It can be seen from the ^{geological} map that these lineations, almost without exception occur in sub-areas 10, 14, 17, 20,. (Fig. 7.). There will be an associated spread in the poles of foliation causing a widening in the girdle of foliation poles. DI5 and DI6 are plots of foliations and lineations from sub-areas 10, 14, 17, 20., and show that the structural complexity in this region completely explains the spread in lineations in DI4 and partially explains the wide girdle in DI3.

The second spread is due to a rotation of the lineations and foliation poles about a north-westerly plunging axis. In DI4 this is demonstrated by the symmetrical dispersion about the maximum. Similarly, in DI3 the poles to foliation are spread along the line cd. This is clearly shown by the shape of the maximum and the 8% contour. This inhomogeneity is due to a systematic variation of the attitude of foliations and lineations over the whole of the area. In the west the foliation dips at about 60° to the west-southwest and the lineation plunges 50° to the west-northwest, whereas in the east the foliation dips 40° to the north-northeast and the lineation plunges $0-5^{\circ}$ to the west-north west.

Neglecting for the moment the fault complex (sub-areas 10, 14, 17, 20) and excluding the faults in the other part of the area, then the area as a whole shows a systematic departure from homoaxiality, and thus has triclinic symmetry. Triclinic structures may arise from an impressed inhomogeneous strain or by superposed, genetically unrelated strains. The evidence which will now be discussed indicates that it is the latter case.

GEOMETRY OF LINEATION PATTERN:

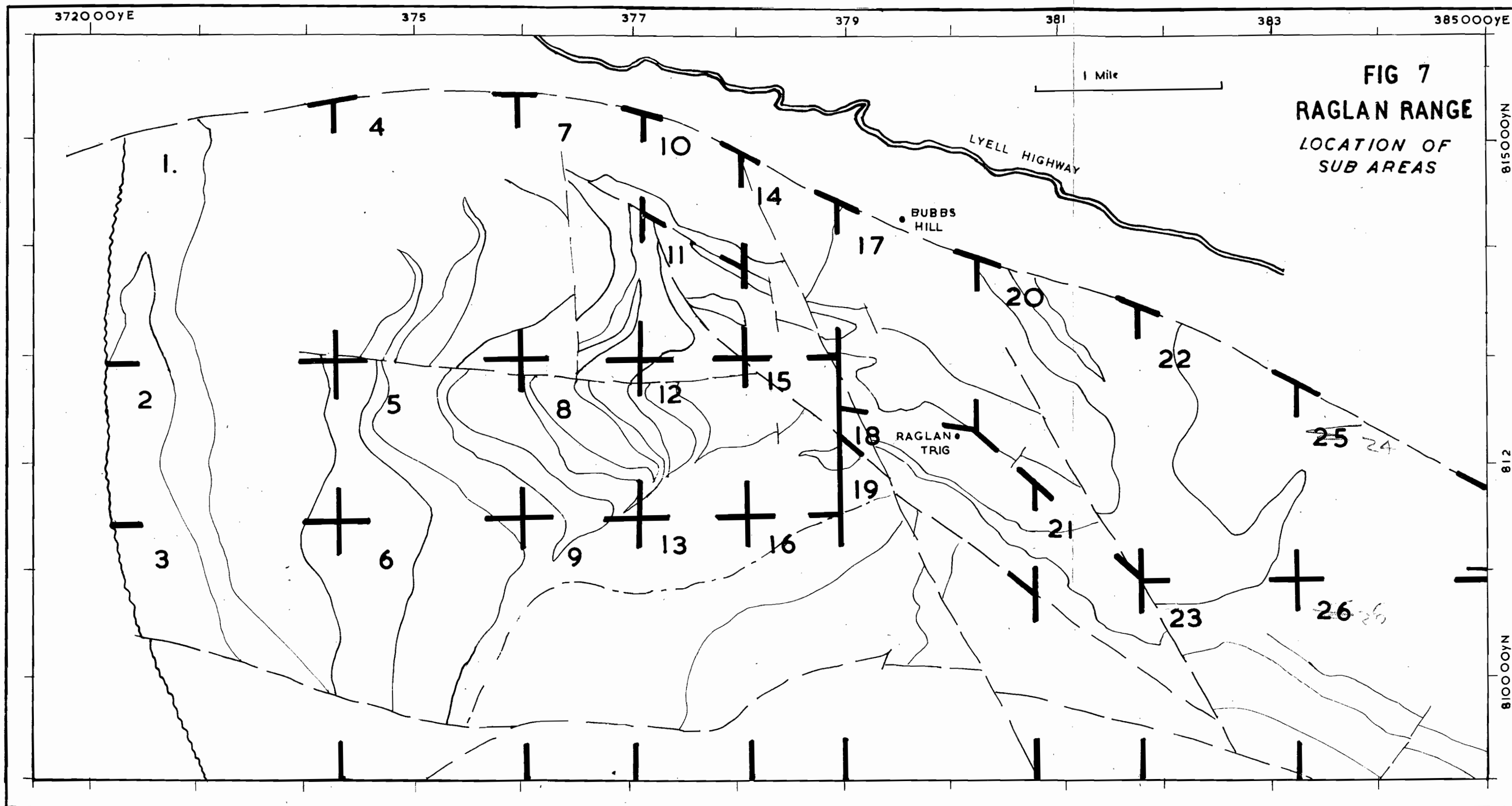
In order to evaluate the systematic departure from homogeneity the area has been divided into 24 sub-areas of about one square mile,

GEOMETRY OF LINEATION PATTERN (cont.)

each of which appear structurally homogeneous (Fig. 7) . A total of only 600 foliations and 600 lineations were taken and the sampling is not good. For example it was possible to take only 10 readings from sub-area 3, and 20 from sub-area 6,. A synoptic β -axis diagram is prepared for the area outside the fault complex. The procedure is essentially the same as that outlined by Weiss (1954 P.14) although a slightly different method was used to prepare the individual stereograms.

Poles to the foliation and lineations ~~/~~ within each area were plotted on individual stereograms. The F (foliation) maxima, and L(lineation) maxima, for each sub-area is then replotted on a synoptic β -axis diagram. The F and L data for all sub-areas are summarised:-

<u>Sub-area</u>	<u>F.max.</u>	<u>L.max.</u>
1	000/40° W (true)	306/33° True.
2	347/50° W	303/40°
(3)	336/64° W	307/44°
4	357/40° W	300/35°
5	358/40° W	305/34°
6	no maxima	
7	359/36° W	301/32°
8	020/30° W	308/29°
9	000/34° W	297/31°
10	no maxima	
11	006/26° W	302/29°
12	031/24° N.W.	296/24°
13	357/36° W	301/31°
14	no maxima	
15	043/20° N.W.	297/17°
16	no maxima	
17	no maxima	
(18)	083/25° N	298/12°
19	no maxima	
20	no maxima	
21	092/29° W W	298/13°
22	046/26° N.W.	299/24°
23	088/30° N.	295/14°
24	081/26° N	296/14°
25	113/41° N	296/2°



The individual stereograms all show a distribution of F poles on a great circle whose pole is the lineation maximum. A distinct F maximum is usually obtained from areas outside the fault complex although not enough readings were taken from 6 and 16 to obtain a decisive maximum. This F maximum corresponds to the pole of the average axial surface of the folds in that area, a corollary of the isoclinal style of folding. The L maximum is the average fold axis of the Precambrian folding. The monoclinic symmetry displayed by the individual stereograms indicates that on the scale of about one square mile the effect of any later deformation (not including faulting) can be excluded.

The average axial plane, and average fold axis for sub-areas are plotted on a synoptic diagram D17. The β -axis around which the axial planes are bent is given by the statistical maximum of all points of intersection of every possible pair of planes. It is $326^\circ/24^\circ$. Poles to the axial planes fall on a partial great circle accounting for the spread of the foliations along the line cd in D13. Consequently the lineation maximum^a, lying in their respective F maximum planes are spread in an arc about the β -axis. This arc is compared with a small circle of radius 20° centred on the β -axis and a great circle inclined at 20° to the β -axis. It best approximates to a great circle.

Recently, Ramsay (1960) has shown that it is possible to deduce the style of folding and the sequence of deformation from a study of the geometry of the disorientation of pre-existing rectilinear lineations due to a later act of folding. Rectilinear lineations on a folded surface folded concentrically maintain a constant angle with the new fold axis and therefore, plot on a stereogram as a small circle centred on the new fold axis. In similar folding the angle between the lineations and the new fold axes changes systematically on moving around fold and the lineations

lineations lie in the one plane. Therefore, they plot on a stereogram as a great circle.

The departure of the locus of lineations from a great circle may be due to one or more of the following factors:-

- (1) The later folding may not be truly similar in style
- (2) there may be more than one phase of folding
- (3) not enough field observations taken to give a unique pattern.

Tabberabberan folding:

Confirmation of the disorientation of the lineations by later folding is readily found from field data. Firstly, there are the minor structures, previously described, that deform the lineation. Secondly, and more striking is the presence of folding in the overlying Lower Palaeozoic rocks.

At the western margin of the Precambrian block, and near Bubbs Hill, the metamorphics are unconformably overlain by Owen Conglomerate Correlate. At these two localities the average dip of the bedding in the Palaeozoic is 30° to the west, and 20° to the north east. This is an anti-clinal structure, Tabberabberan in age which is expressed in the underlying metamorphics by the bending of axial surfaces and fold axes.

The attitude of bedding in the Palaeozoic rocks that flank the Raglan Range on the west, north, and north east, have been considerably modified by the strong faulting associated with the Nelson Valley graben. It was found impossible to define any Tabberabberan fold axis using the bedding measurements on hand. However, from the geometry of the lineation and foliation pattern it can be established that a Tabberabberan anticline axis plunges 24° toward 326° (true). The fold can be located on examination of the attitudes of the foliation on the map, where it can be seen that the crestal trace follows approximately the Raglan Trig. Fault. On the southern side

of the fault the foliation dips south-westerly, and on the northern side dips north easterly.

Unfolding of the Tabberabberan fold is difficult since:-

- (i) there are no outliers of insitu Palaeozoic sediment on the Raglan Range.
- (ii) There are no Tabberabberan lineations developed in the Precambrian, about which the Precambrian structures can be unfolded.
- (iii) the attitude of bedding in the surrounding sediments is unreliable, thus affording no indication of the profile of the Tabberabberan fold.

because of faulting?

In order to deduce the orientation of the Precambrian structures prior to the Tabberabberan, it is, therefore, necessary to assume that the area was homoaxial. This assumption appears quite likely in view of the homogeneity displayed by the fabric on diverse scales. The method of ^uinfolding used is to choose an area with Palaeozoic sediments close ^{by}. The Precambrian structures are rotated about the axis of the Tabberabberan fold so that all the foliation planes are parallel.

The Palaeozoic and Precambrian are then ~~related~~ rotated together about the same axis until the dip in the sediment is horizontal.

The area chosen as a control is sub-area I, where sandstone (strike 012° , dip 35° west) unconformably overlies schists and quartzites (F.maximum $000^{\circ} 140^{\circ}$ W.), (L.maximum $309^{\circ}/33^{\circ}$). Diagram D.18

is a stereographic projection of the L.maximum ^{um} after unfolding about the β -axis. The common foliation planes strike 317° and dip 8° south west.

The lineation spread is considerably reduced and the L.maxima dip gently (about 4°) toward $288^{\circ} - 297^{\circ}$. Therefore, prior to the Tabberabberan Orogeny,

how do you know?

the major part of the Precambrian in the Raglan Range area consisted of recumbently folded slabs of quartzite and schist dipping uniformly at a shallow angle toward the south-west. This statement does not imply that the region has undergone only one phase of deformation, but that the two phases (deduced from the microfabric study) were coaxial.

FAULT COMPLEX: ---Sub-areas 10, 14, 17, 20.

This generalisation does not apply to the inhomogeneous fault complex which may have impressed upon it a deformation which is younger than the main Precambrian movements, but older than the Tabberabberan. Evidence for such a deformation is given by a considerable departure of the lineations from a rectilinear arrangement beneath the Owen Conglomerate Correlate at the Bubbs Hill exposure. Furthermore, the foliation in schist and quartzite dips at 60° to the north-northeast. When the bedding in the sediment is flattened the foliation steepens and dips to the north at about 65° . The lineation then plunges $20-30^{\circ}$ toward 330° . This means that prior to the deposition of the Owen Conglomerate, this region was not homogeneous with the major part of the Raglan Range. A stereographic ^{projection} of 15 lineation measurements from close to the sediment shows a rotation about an axis plunging about 50° to the south east.

This inhomogeneity is a characteristic of the fault complex. The southern half of this complex has a backbone of a thick slab of quartzite striking northwest and dipping northeast. In the northern half is another slab dipping moderately north west. Within these slabs are typically Precambrian folds whose axes plunge into the sector $260^{\circ} - 080^{\circ}$. Both easterly and westerly dipping lineations can be found in the one outcrop. Superimposed on the Precambrian folds are the more brittle style folds described on page (64). It is not known whether these folds are the sole cause of the disorientation of the Precambrian lineation.

The crestal line of the Tabberabberan anticline passes through this complex.

Running parallel to the trend of the complex are two faults of unknown displacement. The fault zones are characterised by by sheared and unsheared breccias, silicification, calcite mineralization and dragging on near horizontal axes. The isolated maxima of lineations dipping steeply to the east (DJ6) is the expression of this dragging.

¹⁵
Specimen 30135¹⁵ a breccia containing fragments of quartzite and muscovite quartzite in a sheared matrix of elongated quartz and twisted muscovite flakes. The surface of movement of these faults is ~~both~~ parallel or slightly steeper than the foliation. Also the fault surface is slightly undulating, a ~~phenomenon~~ phenomenon which may or may not be due to folding. These faults are the oldest in the area and have a different style to the other faults. They are tentatively designated as pre-Tabberabberan faults.

Two sets of Tabberabberan faults (a north north-east set and a north north-west set) cut the area. These are accompanied by close jointing and silicification.

There are possibly four deformations that produce this complex:-

- a. earlier pre-Tabberabberan faulting.
- b. folding which disorientates the Precambrian lineations as that the fabric is not homogeneous on flattening the bedding in the overlying sediments.
- c. the major Tabberabberan anticline and related minor folds.
- d. block faulting.

I prefer this

Mapping of the rock distributions in the complex does not appear to be sufficient to reveal positively the presence of any pre-Tabberabberan movements. A more detailed investigation is required with particular attention given to the internal structure of the quartzite, the pattern of disorientation of lineations especially in small unfaulted areas, and the geometry of the movement surfaces of the faults.

Tectonic Profile:

The average fold axis in the Precambrian is 301° plunging 24° and the Tabberabberan ^{fold} is almost co-axial 326° plunging 24° .

On the whole, the region departs only slightly from a homoaxial condition and quite large areas exist that are actually homoaxial. The map of the Raglan Range was divided into five homoaxial regions and profiles constructed by projection of the lithological contacts onto a plane lying normal to the lineation maximum for that area. The individual profiles were then joined giving the tectonic profile of the Raglan Range. The average axis of projection is 301° plunging 24° . By this analysis, the effects of topography are eliminated and the over-all structure is viewed by looking down the fold axes. Faulting makes axial projection difficult, however many of the smaller faults can be removed by unfauling once the individual profiles are drawn. Major faults are left unfaulted since their displacements are not always known. It should be noted that the projection of the trace of a fault on the ground surface upon any plane does not give the true attitude of the fault. For example, the major fault along the Governor River, although it probably dips steeply, projects as a near horizontal line. Where faulting is complex, construction of a profile is technically impossible, hence the fault complex is left as a blank on the profile.

Presentation of the field data in this form immediately demonstrates the recumbent style of folding that is evident on the smaller scales. The ~~Pre~~^Precambrian structure is seen to be a series of recumbent folds piled one on top of the other. The major lithological boundaries defining the folds ~~is~~^{are} probably bedding.

Directly above the Governor River Phyllite is a series of attenuated quartzite fingers "dangling" in the schist. These fingers are bent into sigmoidal shape curves, a structure that the statistical analysis of foliations did not reveal. This is attributed to the small number of measurements taken in this critical area. The tectonic significance of the attenuation of these fingers is important. Two interpretations ~~are~~^{are}:-

- (i) The quartzite slabs are beds that have been torn from similar bedding lying further to the south-west. This implies large scale tectonic transport by which the Franklin Group moved bodily over the Mayy Group in a north-easterly direction. The layer of schist and phyllite (phyllonite) beneath the quartzite is a surface or zone of detachment.
- (ii) Alternatively, the fingers represent the crests of small recumbent folds closing to the south west. At the extremity of one of these fingers (the one furthest to the south west) the foliation in the quartzite curves right around the tip indicating a fold crest. There is also an increase in the amount and size of folds within the quartzite near the tips. This would not be expected if the fingers were detach^{ed}/slabs. Another indication of fold crests is the bulbous nature of the ~~f~~^{finger}s toward the extremities, a feature found in the crest of a giant recumbent fold in the Moine Series near Strathspey, Scotland (McIntyre 1951).

This condition is midway toward the development of a tectonic inclusion

Adopting the second alternative, ~~then~~ tectonic transport from north-east to south-west presents a more coherent picture. The profile shows that the lowermost folds (probably the first formed folds) are smaller, whereas successively higher folds increase in size upward to almost the dimensions of a nappe. The successively formed folds over-ride the lower ones dragging them into a shape consistent with the sense of movement.

The Raglan Range is not a sufficiently large area to disclose a major, coherent structure, however, on page (126)¹⁵, an attempt at a tectonic syntheses incorporating McLeod's (1955) mapping.

FAULTS.

The Raglan Range is strongly faulted, but in many cases the amount and direction of displacement is difficult to determine. This makes interpretation of the Precambrian structures difficult since structural continuity is the only safe method of correlation. This difficulty can be overcome to some extent by constructing profiles of individual fault blocks and correcting for faulting by moving individual profiles.

This method cannot be used for faults that trend about parallel with the projection plane since these faults will not give a definite line on the projection plane. It is fortunate that the majority of the faults trend at a large angle to the plane of projection of the tectonic profile.

Three dominant trends can be recognised which in chronological order are:-

- (1) Set trending 300° - 310° , and which may pre-Tabberabberan, and which have been described earlier.
- (2) set trending 000° - 030° . These all have small displacements.
- (3) set trending 330° which appear to be normal faults with displacements of the order of 300'-500 feet.

One of the more important faults is the Raglan Trig Fault which extends from coordinates (383000 yards E, 809000 yards N,) on the northern slopes of Elat Bluff past the Raglan Trig, to coordinates (387000 yards E, 81500 yards N,) into the Nelson Valley. The southeasterly continuation was mapped by Spry (1957 A).

It trends approximately normal to the plane of projection of the profile, and so its true nature may be represented on the profile. It appears as a high angle reverse fault, the fault plane dipping steeply to the southwest, and having a displacement of 2,000 feet. The Raglan Trig Fault marks fairly accurately the crestal trace of the Tabberabberan anticline and is possibly synchronous with the folding. Its relation to the other faults is not clear, however it appears that it might be older than sets (2) and (3), but younger than set (1). It trends 310° on the Range itself but swings to 330° in the northern part of the area. The suggestion that the major part of the faulting post dates the folding in the Tabberabberan needs to be confirmed by a more detailed field investigation of the faults.

Two major east-west faults are outlined respectively by the Governor River and the unnamed river flowing parallel to it two miles to the north. The larger one was mapped by McLeod (1957) in the lower reaches of the Governor

River. He considered it to be a dextral transcurrent fault having a displacement of about 1 mile. The displacement of the Mary Group - Governor River Phyllite contact is about 3500 feet in the same direction. The east-west fault to the north is also a dextral transcurrent fault of uncertain magnitude. Strike faulting may explain the sudden disappearance of this fault.

Strong east-west faulting, veering to the south-east marks the line where Palaeozoic (Silurian) sediments butt against the Precambrian rocks. The top of the Raglan Range is 1,800 feet above the button grass plain in the Nelson Valley. Assuming a minimum of 2,000 feet thickness of Ordovician and Siluro-Devonian sediments, then the total displacement on these faults is at least 3,800 feet.

MICRO FABRIC.

SURFACES IN THE MAYY GROUP:

Mayy Group rocks are contorted and fractured on all scales from microscopic to at least macroscopic. This is especially true of the phyllites. The folded surface will be called S1 and successively later surfaces designated S2 and S3.

The S1 surface in some of the more finer-grained phyllites is expressed by the alignment of muscovite flakes parallel to the colour and compositional banding due to variations in relative proportions of quartz, muscovite and graphite. The similar style of microscopic folding is well illustrated in fig. (Plate VI. b); Sp 30106. Minor inflections and fold ~~axes~~ axes persist along the axial surfaces for distances comparable with the size of the hand specimen. On the limbs of the microfolds the muscovite flakes assume an en echelon habit, parallel to the axial surface of the folds. Plate VIa depicts the incipient development of a new surface which is caused by the rotation of the S1 muscovite toward parallelism with the shear planes. This is a stage midway toward the development of a true axial surface cleavage.

With prolonged deformation, many of the S1 muscovites are rotated into the plane of movement creating a new surface S2 which is parallel to the axial surface of the folds in S1 (Plate VI. a).

Plate VI. c shows the typical fabric of the Mayy Group phyllites in this area. Crystallisation of new muscovite accentuates S2 so that it now is by far the dominant surface. The muscovite is larger and shows a high degree of preferred orientation, the cleavage flakes aligned parallel to S2. The rock possesses a schistose texture due to alternating quartz and muscovite

rich layers. S1 is still clearly visible as curved trails of small muscovite flakes preserved in the quartz rich layers.

In the quartz-muscovite schists usually S1 is present but S2 is not always visible. All stages in the development of S2 can be seen in slide 30I36. S2 is ~~is~~ usually dominant although the rock does not possess a good mesoscopic foliation.

The S2 surface does not appear to be developed in the quartzite, due to the lack of muscovite. Petrofabric diagram D10 is a plot of the 001 cleavage of muscovite of specimen ³⁰¹¹⁰ (434) measured in the ~~ac~~ fabric plane. It shows a tendency toward a girdle with a 24% maximum. ~~The~~ The mica plane S1, is parallel ~~to~~ the surface defined by trails of graphite particles, and layers having different average grain size.

The strong degree of preferred orientation of muscovite parallel to the folded surface in Plate (VI b) shows that S1 is not sedimentary bedding but an older tectonic surface. However, it is probable that the lithological banding represents the original bedding and this is supported by the following evidence.

1. Trails of graphite in phyllite and quartzite which are parallel to the lithological banding, are taken as a good indicator of sedimentary bedding.
2. The occurrence of ripple-marks and current-bedding in the Mavy Group in other areas (Spry 1957A) (~~1957B~~) proves that bedding can still be preserved.
3. The simple pattern, high maximum ^{um} of 24% and monoclinic symmetry of the mica diagram D10 suggests that S1 is the first deformation to which this rock has been subject. The petrographic evidence from specimen 30III, (p 29) may give support to this statement.

Sedimentary bedding is here defined as S_0 , and tentatively correlated with the lithological banding. It appears that S_1 and S_0 are closely parallel, although the mica girdle in D10 does not exactly correspond to the S_0 fabric plane, being tilted by about 5° . ✓

A third and later surface, S_3 is found mainly in the phyllites, occasionally in the quartz muscovite schists and rarely in the quartzite. S_3 takes the form of micro fracture cleavage sub-parallel to the axial surfaces of micro folds which contorts S_2 . The fractures are irregular sub-parallel, varying in length from minute to about 5 c.m.s, are generally confined to the muscovite rich layers in schists and phyllite. Plates VId and VIe illustrate S_3 . In plate VI S_1 and S_2 and S_3 are all clearly visible whilst in Plate VIe, S_1 is present but not visible since the section is cut parallel to the lineation and normal to S_2 .

Microscopically, three types of lineations are recognisable in the Mary Group. Lineation in phyllites is due to the intersection of S_1 and S_2 . In hand specimen it is expressed as small parallel crenulations on the foliation surface. It is probably due to a minor tendency for the rock to split along S_1 . Lineation in the quartzite is due to dimensional elongation of quartz grains and to porphyroblasts of chlorite. The chlorite is flattened in the plane of the foliation and elongated in the lineation - the approximate axial ratios are $a:b:c :: 4:10:1$

The lineation in quartzite is also the axis of a quartz girdle of (0001) poles (D. 11)

2.

SURFACES IN THE GOVERNOR RIVER PHYLLITES:

The fabric of the Governor River phyllites is structurally more evolved ~~than~~ that of the Mavy Group.

S2 is the dominant foliation, being defined by a metamorphic banding and a preferred orientation of muscovite and to a lesser extent biotite. The metamorphic banding due to the alternation of quartz and muscovite-rich layers is coarser and generally more continuous than in the Mavy Group phyllite. S1 is still visible, expressed as curved sigmoidal, or crumpled surfaces oblique to S2 and preserved in the quartz rich layers (Plate VI, fig). Occasionally, S1 is completely obliterated, or more rarely it may be prominent where the S1 fabric is preserved on the crest of a fold.

If the amount of obliteration of S1 is a criterion of the degree of deformation, then the Governor River Phyllite is more sheared than the underlying Mavy Group and the overlying Franklin Group. During this shearing the earlier fabric was broken down, and the metamorphic change is retrograde. The Governor River Phyllite can therefore, be regarded as a phyllonite.

Micro crenulations similar to those that deform the foliation in the Mavy Phyllite are present but not as common. The fractures related to these crenulations S3 are not as extensive and usually affect only the one muscovite layer. Larger crenulations, similar in style to the joint drags are common in some slides. These take the form of asymmetrical, angular "ripples" of the foliation with a wavelength and amplitude of about 5 m.m. and 0.6 m.m. respectively.

No cleavage or mineral development is associated with this late stage of deformation.

All these surfaces and crenulations are grouped together as S3 although certainly S3 includes genetically unrelated surfaces which may range in age from Precambrian to Tabberabberan.

3. SURFACES IN THE UPPER FRANKLIN GROUP SCHISTS:

The surface in the coarse quartz-muscovite schists, corresponding to S2 of the phyllite is the dominant foliation in these rocks. In thin section, S2 is not as distinct as in the phyllites. It is due to the concentration of platy minerals into layers, and the parallel arrangement of the cleavage planes within these layers. Rarely is S2 a planar, continuous surface because of the following factors:-

1. Post-tectonic crystallisation of large muscovite which is mostly mimetic, serves to reduce the high degree of preferred orientation of muscovite found in the Governor River Phyllites.
- II. S2 is bent around the porphyroblastic minerals namely garnet, albite, amphibole. (~~Photo 30~~)
- III. The effect of S1, which does not appear to have been obliterated to the same extent as in the Governor River Phyllite.

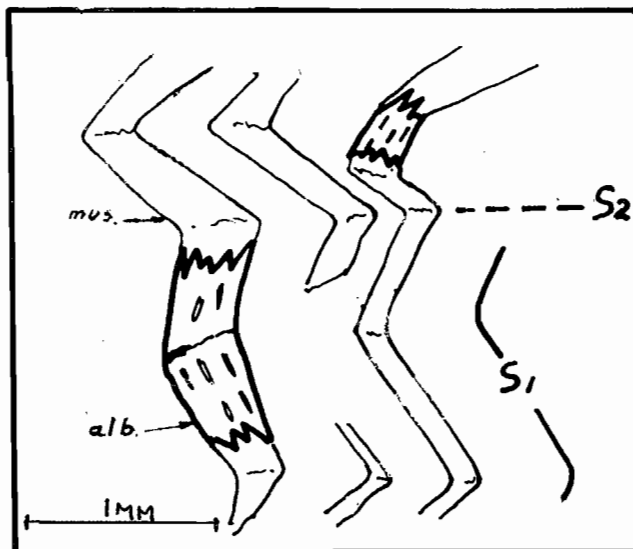


Fig 8b.

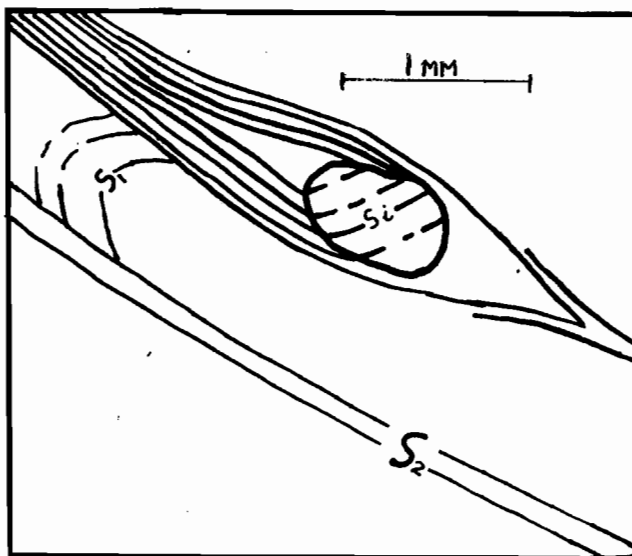


Fig. 8a Relationship
between Si albite, S₁, S₂.

S1 is defined by sheaths of muscovite flakes, not as isolated small flakes as is the case in the Governor River Phyllites.

In the more muscovite-rich layers S1 can often be traced as a continuous discrete crumpled surface for a distance of up to 10 m.ms. (slide 30114), however, most of the muscovite has axial surface relationship with respect to S₂, either being present in the axial surface itself or, more commonly on the limbs of isoclinal micro folds with large amplitudes and small wave-lengths (0.8 and 0.2 m.m. respectively).

Another type of surface found in the schist is the internal surface S_i, within albite porphyroblasts. These are helictic inclusions inherited from a surface older than S₂. Their form will be described later. A few porphyroblasts of albite were found in which the S_i muscovite was uncrumpled and continuous with the remnant S1 muscovite surface in the ground mass. The S₂ muscovite forming the schistosity flowed around the porphyroblast. These relations between S1, S₂ and S_i are schematically represented in (fig. 8 a). Such a fabric is interpreted thus:

- i. Tectonic movement along shear surfaces accompanied by growth of muscovite producing S1:
- ii. post tectonic growth of albite enveloping portion of S1. All albite is post tectonic to S1. (Page 108).
- iii. Second phase of tectonic movement which deforms S1 and produces S₂. Porphyroblast did not rotate or become detached from S1.

Upon this interpretation rests the correlation of the S_i of albite with S1.

All surfaces that deform the S2 foliation, such as joint drags and minor crenulations are collectively termed S3.

4. SURFACES IN THE UPPER FRANKLIN GROUP QUARTZITE AND MICACEOUS QUARTZITE

The main surface in the micaceous quartzite is folded into micro isoclinal folds, chevron folds and asymmetrical drag folds all of which are similar in style. Wavelengths and amplitudes are of the order of 2 m.m. - 2 cm. The axial surfaces of these folds are parallel to each other and are regularly spaced about 1 c.m. apart. The angle between adjacent limbs on either side of the axes is fairly constant in the one slide but varies from nearly 0° (i.e. parallel limbs) to about 60° . The folded surface is an alternation of quartz and muscovite-rich bands having an average thickness of 1-2 m.m. This surface is correlated with S1 because:-

- (i) it is the folded surface.
- (ii) all gradations exist between this fabric and the fabric of the schist, as the folds become strictly isoclinal.
- (iii) In slide ³⁰¹⁴⁵ ~~131~~ are several albite porphyroblasts with an undeformed S1 continuous with the folded surface. (Fig. 8b.).

Generally, only one foliation is visible in the quartzites which is defined by the orientation of the mica. Lithological banding also occurs, examples of which have been described on page (55).

M I C R O F A B R I C (cont.)5. PETROFABRIC ANALYSIS OF A FOLD:

In order to investigate the relationship between S1 in the quartzite and S2 in the schists, and to determine the style of deformation a brief petrofabric study of the recumbent fold in quartzite near the old timber mill (fig. 6) was undertaken.

Oriented specimens were collected from three positions, 30I37 from the lower limb in the quartzite, 30I38 from the hinge area in the quartzite where the foliation is overturned with respect to the previous position, and 30I39 from the hinge area of the fold in crenulated micaceous quartzite and the adjacent schist. The positions are shown in figure (6 , Page 6) Quartz and muscovite diagrams were prepared from thin sections cut normal to the lineation. The fold axis is an axis of rotation with a plane of symmetry normal to it. Macroscopic fabric axes a, b, and c are assigned to the fold so that b is the fold axis which is parallel to the lineation. The ab plane is the axial surface of the fold and the ac plane is the plane of symmetry normal to the b axis and to the ab plane. The lineation in specimens (30I37, 30I39) lies within 3° of the b fabric axis. In the third specimen 30I38 the lineation deviated from by 20° of plunge due to dragging on a small nearby fault. It is assumed that the later brittle style of deformation does not modify the micro fabric but simply externally rotates it. Consequently the plane of the thin section which is cut normal to the lineation, in its correct orientation, lies in the ac plane of the fold. For ease in comparison the petrofabric diagrams are orientated so that the observer looks down the plunge of the lineation and the axial surface

of the fold (which is known approximately) ^{at} ~~each diagram~~ are arranged so that they are parallel. on each diagram.

Mica fabric.

The mica diagrams D1, D3, D5 are the poles to the (001) cleavage planes of muscovite and show that the lineation is an axis of rotation and an axis of a partial girdle. D1 from the limb of the fold shows a high concentration of 34% with a definite spread in the ~~ac~~ fabric plane. The spread of about 40° on either side of the maximum is symmetrical which probably reflects the absence of any tendency toward rotation of the mica surfaces in this region of the fold. The maximum defines the S1 surface.

In the hinge of the fold in quartzite, the mica surface S1 is rotated through 110° which is consistent with the dip of the foliation having changed from 24° to the ^{west} ~~W~~ in the limb to dipping 80° to the South west and overturned. The extent of the girdle spread in the ~~ac~~ microfabric plane has increased but there is still a distinct break in the girdle in the foliation plane. This greater spread is due to a slight undulation of S1 which can be seen in thin section. There is no indication of the development of a discrete surface parallel to the ~~ab~~ fabric plane, although an isolated 2% area normal to the ~~ab~~ plane is present.

Developed foliation

A common feature of D1 and D3 is that the colour and compositional banding which is designated So, is oblique S1 indicating that these are distinct surfaces (see P. 65) The inclination of So to S1 is an average of 15° and maintains the same position with respect to S1 as the surface is folded.

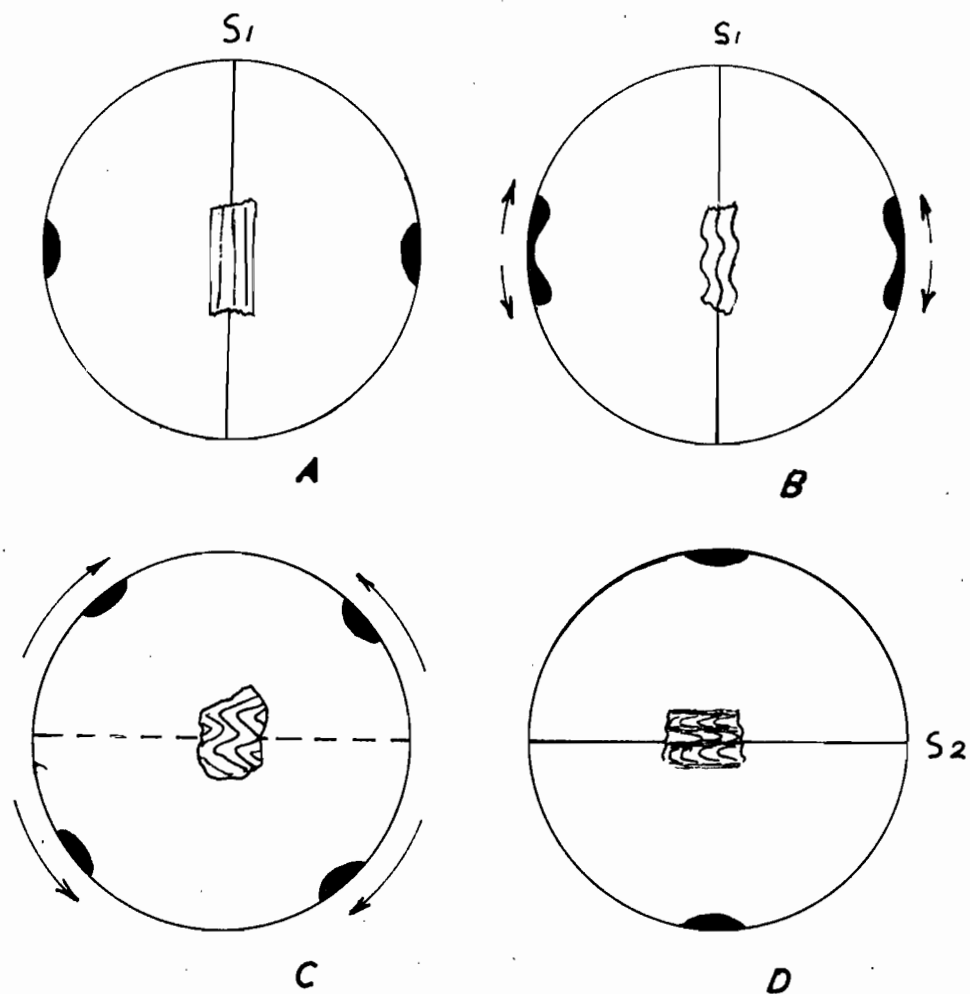


Fig.9 Movement of muscovite maxima associated with quartzite-schist transition.

Specimen 30139 from the micaceous quartzite band has microscopic and mesoscopic zig-zag folds in S1. These folds have fairly angular hinges and straight limbs so that the axial surfaces are easily located. The average axial surface of the minor folds (S2) is marked on D5. The mica diagram has a maximum MI of 10%, and a smaller maximum of MLI of 6% defining a pair of statistical planes symmetrically disposed about S2. A number of micro folds drawn from the slide are inset in D5 in their correct orientation. It is clear that the predominance of micas on the limbs of these folds accounts for the two statistical planes. From the shape of the folds it would appear strange that the girdle is not complete, however, the muscovite has been post tectonically recrystallised as a result of which the muscovite on either limbs butts abruptly into each other at the apex.

A third maximum MIII of 8% is centred on the pole of the axial surface of the micro folds representing occasional muscovite growing within this plane.

Although a petrofabric diagram was not prepared from the adjacent schists, the typical arrangement of the muscovite has been outlined. It is anticipated that the diagram would have two strong maxima of 001 poles normal to S2 and a complete girdle, weak in the plane of the foliation. The mica diagrams suggest a textural gradation exists between the quartzites where S1 is dominant to the schists where S2 is dominant. The changes in the mica fabric observed as one proceeds from the quartzites, across the micaceous quartzite in the hinge area and into the schist are schematised in Fig. (9).

- A. The mica fabric of the quartzite in the hinge of a fold has a maximum on either side of the S1 surface.
- B. The S1 surface is crumpled near the contact with the micaceous quartzite causing the maximum to split and diverge.
- C. With an increase in the muscovite content more intense crumpling occurs causing the two maxima to rotate further.
- D. In the schist, the crumpling of S1 assumes an isoclinal style. The maxima now coalesce and become normal to the new surface S2, which is parallel to the axial surface. Some of the older S1 muscovites that still define the S1 surface produce a complete girdle.

Throughout this transition, the symmetry remains ideally monoclinic, the ac plane being the plane of symmetry.

Quartz Fabric.

The quartz fabric is radically different from the mica fabric in that it maintains approximately the same orientation irrespective of the tectonic position. The quartz {0001} diagrams D2, D4 and D6 are all strikingly similar in the following respects:-

1. There is a sharply defined girdle of 0001 axes with an axis almost parallel to the megascopic lineation. The girdles are not strictly in the ac micro fabric plane but depart by 10° and 8° (D2, D6 respectively) The symmetry is basically monoclinic with a tendency toward triclinic.

2. A single unusually strong peripheral maximum is present in each diagram. The maximum concentrations of D2, D4 D6 are respectively 13%, 8% 8%.
3. The lines joining the point maxima to the centre of projection make angles of 15° (D2), 20° (D4), 28° (D6) with the ab plane. Although the position of the ab plane is not known exactly, it is simply used as a reference plane. The orientation of the maxima remain more or less constant in the three sections analysed. Such a fabric is not capable of being unrolled and is homogeneous.
4. A break (D2,D4) or a distinct weakness (D6) occurs in the girdle in the region 90° from the maximum. This weakness also has a constant orientation in the three sections and again points to the homogeneity of the quartz fabric. This phenomenon, plus the sharp girdle and the peripheral maxima cause the quartz diagrams to imitate mica diagrams in general.

Minor differences between the diagrams do occur but these are systematic changes. The girdle becomes more entire and widens the maximum concentrations drop from 13% to 8% and smaller non-peripheral sub-maxima appear.

Mode of deformation:

The inhomogeneity of the mica fabric and the homogeneity of the quartz fabric appear to be incompatible. Considering the muscovite, the fabric is capable of being unrolled about the b axis giving a homogeneous fabric for the whole fold. At the two positions in the quartzite, the tangent to the fold is given by the micaplane. These are criterion of concentric folding (Knopf and Ingerson P.78, Ball (1954).

However, the quartz fabric is not consistent with a concentric fold. The quartz fabric in a concentric fold will be identical in pattern but all points on the fold will have an identical relationship to the tangent to the fold. Taking the fold as a whole, the quartz fabric will be inhomogeneous because of the inhomogeneous stress field. For a similar fold "the fabric of the quartz grains will be identical in all parts of the fold and the same set of maxima will be ⁱⁿ the same relative positions." Ball (P.276) This is the relationship portrayed by the fold under discussion.

In view of this apparent anomaly, three types of deformation must be considered.

1. Concentric folding followed by post tectonic reorientation of quartz.
2. Similar folding with S₁ remaining passive.
3. Concentric folding followed by similar folding

1. The fold assumed its present profile by concentric folding during the S_2 phase. An unrollable quartz fabric was produced in the inhomogeneous stress field. During a later tectonic stage the quartz was reoriented under a homogeneous stress field adopting its present fabric, whereas the muscovite failed to reorientate. Crompton (1958) described a folded specimen from the Moine Schist in which the quartz fabric is ~~inhomogeneous~~ but the mica fabric is unrollable. He interpreted the data in the above manner. This does not apply in this case because:-

- i. The quartz and mica girdles are coaxial.
- ii. A deformation that was sufficiently intense to produce a new quartz fabric would be expected to leave some imprint on the mica fabric.
- iii. There are no post-~~Pre~~cambrian folding movements that re-orientates quartz.

Not strong

2. The style of folding is similar, with flow occurring along statistical flow surfaces sub-parallel to the axial surface of the fold. These surfaces could well be defined by the grain shape of the quartz, rather than the muscovite. In specimen ³⁰¹³⁷ (62) on the limb, the dimension ratios are 2.9: 2.4: 1. The grains are flattened in the plane of the S_1 foliation and elongated in the a fabric axis. This elongation gives the rock a very feeble lineation which can be seen (through a binocular microscope) on the foliation plane normal to the b lineation. In specimen ³⁰¹³⁸ (67) in the hinge the dimensions ratios are ~~1.2: 1.7: 1~~ with the longest

1.2 : 1.7 : 1

dimension parallel to the lineation and in a section normal to this, seen to be slightly elongated in the a fabric axis.

It is postulated that these statistical surfaces (S_2') exist throughout the fold and are analagous to the surfaces produced by the dimensional orientation of muscovite sub-parallel to the axial surface in a cleavage fold. The orientation of S_2' is influenced by the orientation of the S1 muscovite and lie parallel to the S1 foliation in the flanks, but parallel to the axial surface of the fold in the hinge area.

The quartz ^{is} ~~is~~ orientated under the monoclinic stress field giving a monoclinic fabric that is homogeneous at all positions on the fold.

The pre-existing foliation S1, which is expressed as the alignment of muscovite, behaves as a passive surface, analagous to the bedding surfaces in a similarly folded shale. The S1 foliation internally rotated about an axis by simple monoclinic shear. This axis is given by the intersection of the old S1 foliation and the new shear surface, S2 (Weiss 1955) which in this case happens to be almost parallel to the fold axes. Therefore, the symmetry remains monoclinic, with weak tendencies toward triclinic symmetry.

3. This hypothesis explains the petrofabrics adequately. However, folding in a similar manner alone does not explain the difference in profiles between folds in quartzite and folds in schist. A minor phase of concentric folding at the onset of the S2 folding answers this problem. Such a sequence is what might be expected in view of the pre-existing surfaces of potential slip if suitably orientated; and also in view of the vastly differing competencies (viscosities) of the schist and quartzite.

A characteristic feature of the quartz diagrams is the single, peripheral maximum. In D2, this maximum lies in, ~~and~~ parallel to the (a) microfabric axis, thus corresponding to maximum I of Fairbairn (1948-P.203). This also ~~lies~~ ^{parallel} to the S2 surface. The microfabric and grain elongation is very similar to a mylonite (Turner 1948, P.203) which is formed by extensive unrestricted transport upon one set of parallel surfaces. At the advent of similar folding, deformation in the quartzite proceeds by finely dispersed viscous flow movements such as intergranular slip, intragranular slip, solution and recrystallisation.

6. FABRIC ANALYSIS OF A PSEUDO RIPPLE MARK:

(30I40)

Plate VIIIc is a slab of white quartzite on the surface of which are a series of structures resembling sedimentary ripple marks. The ripples have parallel axes, an average amplitude and wavelength of 0.5cm. and 2.3 cm.. In profile they are rounded and slightly asymmetrical.

46. FABRIC ANALYSIS OF A PSEUDO RIPPLE MARK: (cont.)

A good streaming type lineation is parallel to the ripple axes, and in profile it can be seen that the ripples are merely cylindroidal undulations of the folded surface. These two features indicate a tectonic origin.

The specimen comes from the hinge of a large recumbent fold exposed in the timber track cutting, $\frac{3}{4}$ of a mile from the Lyell Highway. The lineation plunges 22° toward 305° (true) and the foliation is vertical, so that the specimen occupies a similar tectonic position to specimen 30I38. The purposes of the fabric analysis is to give an explanation of the creulation, and to compare the fabrics of 30I38 and this specimen. The petrofabric diagrams are prepared from sections cut normal to the lineation and oriented so that observer looks down the plunging lineation and the foliation is vertical.

Mica Fabric:

Diagram D7 is for muscovite (001) poles with an inset sketch of the specimen. A complete sharp girdle with four sets of maxima are apparent. The girdle axis b is co-axial with the lineation L. In thin section S_0 is disclosed by a banding due to different grain size and to slight variation in the muscovite content. This is the folded surface. S_1 is parallel to S_0 and is exposed by the parallel or en echelon arrangement of large (0.2 m.m.) muscovite in S_0 . The S_1 muscovite is usually developed along the micro-lithological changes. S_1 , therefore, appears as a discrete surface with an average spacing of 3m.m. It is

defined on D7 by maximum I of 4%.

The closely adjacent maxima M II, M III, M IV. indicate that the majority of the muscovite is oriented with 001 cleavage, about normal to the average direction of S1, thus producing S2 which is an indistinct plane of parting. It is the net result of two mica surfaces corresponding to M III and M IV which are symmetrically disposed about the S2 plane.

The intersection of S1 and S2 is responsible for the strong streaming type lineation and the pseudo ripple marks are crenulations of S1 caused by differential slip along the S2 shear surfaces. They are thus minor similar folds.

Quartz Fabric.

The quartz diagram shows a wide girdle of 0001 axes having two main peripheral maxima of 5%. Other smaller maxima are present. The axis of the girdle is removed by 15% from the lineation so that the b-fabric¹⁵ axis not coaxial with the megascopic lineation, L. Both quartz and mica diagrams each show fairly good monoclinic symmetry with even a tendency toward orthorhombic symmetry. However, the fabrics taken together show triclinic symmetry. Such phenomena have been discussed separately by Ramsay (1960) and Weiss (1955) who maintain that although the symmetry is triclinic, the deforming forces are still homogeneous. The triclinic symmetry arises from the fact that the S1 and S2 phases of folding were not exactly coaxial.

Significance of the Fabrics.

Comparing the fabrics of this specimen with specimen 30138, which occupies a similar tectonic position, two interesting features emerge:-

1. The quartz fabrics appear almost identical in pattern and orientation. This confirms the conclusion reached before that the quartz fabric is homogeneous irrespective of the tectonic position.
2. In this fold, deformation has taken place by slip along discrete mica surfaces, whereas in the previous example (30138) deformation was by dispersed flow along statistical planes defined by the shape of the quartz grains.

7. FABRIC OF MARY QUARTZITE AND "FINCHAM" QUARTZITE:

Included for comparison with the Franklin quartzites is a fabric diagram of a Mary Group quartzite D11, specimen 30110, and of a "Fincham" quartzite D9, specimen 30123.

The quartz diagram of the "Fincham" quartzite is very similar to those of the Franklin Group. This similarity is in harmony with the conclusion above. The Mary quartzite is very fine-grained and so D11 cannot be classed as reliable. However, it shows that the megascopic lineation is a quartz girdle axis and the concentrations of maxima are considerably lower than in the Franklin Group. The significance, if any, of the crossed girdles is unknown, and a test for homogeneity and a further investigation is required before comment can be made.

8. CONCLUSIONS:

1. Two major phases of deformation, represented by S1 and S2 respectively, are recognisable from the microfabric study. These closely approximate to coaxial deformations and so the fabric is essentially homoaxial, and possesses slight departures from monoclinic symmetry.
2. S1 is probably the first deformation impressed upon the Mayy Group and the Franklin Group in the Raglan Range area. Consequently, S0 is probably bedding.
3. Folding in the area is related to the S2 deformation. Nothing is known of any possible S1 folds.
4. The dominant foliation in the schist is not the same as the dominant foliation in the quartzite. Foliation in the schists is axial ~~surface~~ to the S2 folds. Foliation in the quartzite is the preserved older foliation related to the S1 deformation and during the S2 deformation it was folded.
5. Folding in the schist is similar in style, and in the quartzite it is a combination of similar and concentric styles.

6. Lineation in the quartzite is due to the intersection of S_0 and S_1 surfaces, and also the axes of folds in the S_0 and S_1 surfaces. Lineation in quartzite is therefore of two different ages.
7. The quartz girdle is not directly related to the mesoscopic lineation, but due to a coincidence of nearly coaxial deformations the girdle axis and the lineation are almost parallel.
8. Lineation in the schist is mainly the intersection of S_2 surface with the S_1 and S_0 surfaces.
9. The Mary Group has received the same deformations as the Franklin Group, but to a less intense degree.

RELATION BETWEEN METAMORPHISM AND STRUCTURAL DEFORMATION

At least three phases of structural deformation, represented by the surface S1, S2 and S3 are recognisable from the microfabric study. The petrographic criteria for establishing the time relationship between time of mineral crystallisation and the tectonic phases are outlined in the following section.

Garnet:

Texturally five types of garnet are recognised :-

- 1.) Garnet having inclusions of quartz grains arranged in symmetrical, sigmoidal lines. These garnets are xenoblastic, commonly rounded porphyroblasts containing from 10% to 90% by volume of included quartz (Plate VII, a, b). Although the Si (the surface within the crystal) is not continuous with Se (the surface outside the mineral), the recurring "snow-ball" arrangement indicates that these garnets have grown while rotating during the S1 tectonic phase. These are synkinematic to S1.
- 2.) Synkinematic garnets in some cases have a euhedral rim which has few inclusions and with no orderly arrangement (Plate VII b, c). This is taken to indicate that the synkinematic garnets continued to grow during

the late stages of the synkinematic field, ^{or even post-} kinematically to the S₁ phase.

- 3.) In two slides (~~Plate VII d.~~) are garnets converse to type 2 (Plate VII d.) The core is idioblastic, fresh, and almost completely devoid of inclusions. The rim has a rounded outline with abundant inclusions which are elongated parallel to the circumference of the porphyroblast. Such a zoned garnet may have resulted from pre kinematic followed by synkinematic growth.
- 4.) Plate VII e) illustrates idioblastic to sub-idioblastic, fractured garnets containing only a few inclusions with no orderly arrangement. There is no definite indication as to their relationship with S₁, although the garnet is similar in appearance to the post kinematic rim of type 2. On the other hand it may have formed at a time when the foliation had not yet developed.
- 5.) Garnet with up to 90% included quartz in which the Si forms straight lines or slight curves (Slides 30I42, 30I20, 30II7) These garnets are probably post kinematic, but could possibly be deformed synkinematic garnet.

Garnet porphyroblasts are invariably wrapped by S₂, and were thus present before the S₂ phase. Rectangular cracks that do not keep the same orientation from crystal to crystal, and

small dispersed fragments (Plate VII e) bear testimony to a post crystalline deformation.

There is evidence to suggest that some of the garnet has been chloritised in the interval between S_1 and S_2 .

Slide (30143, shows a smeared-out bundle of quartz granules set in a chloritic matrix. This can only be recognised as garnet by the presence of similar but undeformed aggregates of quartz, chlorite and garnet in the same slide.

In summary, the crystallization of garnet is prekinematic with respect to S_2 and synkinematic with respect to S_1 and a possibility that it has entered the pre and post kinematic field of S_1 .

Albite -

Two textural types of albite are present :-

- (1) Albite with helicitic Si composed of dusty graphitic inclusions:
- (2) Albite with helicitic inclusions of metamorphic minerals such as quartz, muscovite, garnet and biotite.

The Si of type 1 forms straight lines or curves which may be gently undulating, sigmoidal or contorted (Plate VIIb). The inclusions in type 2 are generally in straight or gently curved trails. The quartz grain inclusions are elongated by as much as 6 : 1. (Plate VII f).

The internal surface in albite represents the remains of a pre-existing folded surface preserved in the porphyroblast. On page 89 Si was correlated with Si.

Type 1 albite is dominant in the Governor River Phyllite, but these give way to type 2 albite which are dominant in the remaining portion of the Franklin Group. In the transition zone both types of albite can be found in the same slide and both kinds of inclusions in the same porphyroblast. The two internal surfaces are always parallel, and on the evidence available there is nothing to suggest they are anything but the same surface.

Similarly to the garnet, S_2 wraps around the albite porphyroblast. The albite is, therefore, pre-kinematic to S_2 and post kinematic to S_1 .

Muscovite -

Muscovite occurs in dimensionally oriented flakes forming the foliation, and as inclusions in albite. Three types can be differentiated by size and habit.

- 1.) Helicitic inclusions in albite are small flakes varying from 0.05 to 0.6 m.m. in length, depending on the size of the albite. Graphitic muscovite is usually found in those porphyroblasts in the Governor River Phyllite, and clean muscovite occurs in the higher schists. These muscovites are pre-albite.

- 2.) S₁ muscovite: Where still remaining, the actual S₁ surface is composed of very small flakes (0.03 m.m. average length). Although the surface is bent, much of the individual muscovite is straight and sub-idioblastic. Such muscovite is probably due to mimetic re-crystallisation.
- 3.) Original S₂ muscovite: The dominant surface in the Governor River Phyllite is defined by stringy layers of muscovite flakes averaging 0.3 m.m. long. The form is illustrated in Plate (VI g, VII b). The flakes are often curved. Dusty graphitic inclusions and iron staining are common. These are S₂ muscovites, probably synkinematic to S₂ phase of deformation.
- 4.) Mimetic S₂ muscovite: In that portion of the Franklin Group, excluding the Governor River Phyllite the muscovite that defines the foliation is different from type 3. It occurs in thick tabular clear crystals, ranging from 0.4 m.m. to 10 m.m. in length. The individual crystals are bent only where they are affected by the still later S₃ surface. Where the muscovite band curves around a porphyroblast, the crystals are smaller, unbent and often sub-idioblastic. The flakes form interlocking or fan-shaped aggregates, commonly with cross grain flakes (Plate VII g).

This muscovite is post kinematic to the S_2 phase and is mimetically recrystallised type 3 muscovite.

Three periods of muscovite crystallisation are proposed:

- i. Associated with the S_1 stage of deformation
- ii. Synkinematic with respect to S_2 , accompanied by mimetic recrystallisation of S_1 muscovite.
- iii. post kinematic with respect to S_2 which is largely mimetic recrystallisation of S_2 muscovite.

Biotite:

Three types are present :-

1. Helicitic inclusions of biotite are found in albite in the biotite schists. This biotite crystallised early, along with the S_1 muscovite.
2. Plate VII h) illustrates the porphyroblastic habit of biotite. The porphyroblasts are relatively free of inclusions, sub-idioblastic and wrapped by S_2 muscovite, and are thus pre-tectonic to S_2 .
3. Most biotite is associated with S_2 phase of deformation. In the Governor River Phyllite for a few hundred feet above the contact with Mary Group, it occurs as small irregular plates (average

0.1 m.m. dia.) These are parallel to the stringy S_2 muscovite but often slightly cut across them and so appear younger.

4. Biotite in the biotite schists, thought to be genetically related to the amphibolites have a habit identical with the S_2 mimetic muscovite.

Biotite, therefore, has a crystallisation history similar to that of muscovite. The textural types indicate that there was synkinematic and possibly post kinematic (type 2) crystallisation with respect to the S_1 phase, and post tectonic with respect to S_2 . The second period may have proceeded simultaneously with the post-kinematic crystallization of S_2 muscovite.

Chlorite:

Secondary chlorite (probably penninite) is an alteration product mainly of garnet but also muscovite and biotite. Primary chlorite occurs in three forms.

- 1.) Porphyroblasts of chlorite occur in the lower part of the Governor River Phyllite and in the Mary Group. (Slides 30I09, 30I44). In slide (30I09) it is elongate (0.6 m.m.) in the direction of the lineation. The porphyroblasts consist of one xenoblastic crystal containing inclusions of quartz and rutile. They closely resemble the biotite porphyroblasts in Plate

(VII h) in that S_2 flows around them. This chlorite is prekinematic to S_2 and probably related to the S_1 phase of deformation.

- 2.) Primary chlorite (probably prochlorite) occurs in the coarse Franklin schists and quartzites in slides 30I42, 30I47, 30I45, 30I18, 30I46, / where it takes the place of post-tectonic S_2 muscovite. It occurs in masses composed of weakly oriented sub-idioblastic interlocking laths, very similar in habit to post kinematic S_2 muscovite. The crystallization of this type of chlorite is mostly mimetic after the dominant foliation, although the degree of preferred orientation does not appear to be as strong as the muscovite.

Quartz:

Quartz probably has had a continuous crystallisation history commencing from pre-tectonic to S_1 . It occurs in the following habits :-

- 1.) Inclusions in albite and garnet.
- 2.) Pressure shadows of garnet and albite porphyroblasts.
- 3.) Fractures ⁱⁿ of granulated porphyroblasts.
- 4.) Layers parallel to the S_2 foliation. The petro-fabric analyses show that the quartz re-orientation is related to S_2 phase of deformation.

- 5.) Quartz veins that have been folded along with S₁.
- 6.) Quartz veins that are fissure filling Tabberabberan fractures.

Kyanite:

Small fragments of kyanite are found in Slides 30I33, 30I17. The fragmentary nature is taken to indicate a pre-S₂ age; it is probably synchronous, or closely follows the garnet.

Tourmaline:

Two generations of tourmaline are evident :-

- 1.) Porphyroblastic green tourmaline is present in slide 30I48. In the plane normal to the lineation they are rounded, average 1 m.m. dia., and are pre-kinematic to S₂.
- 2.) Idioblastic needles are a common accessory in the upper Franklin Group where they grow in rosettes in the S₂ foliation. These are post tectonic to S₂.

Amphibole:

- 1.) The amphibole in the knotted amphibolite (30I32) is wrapped by the S₂ foliation, and is thus related to the S₁ phase.

- 2.) Amphibole in the amphibolite is included with garnet and in the sheared amphibolite there is a good dimensional orientation of amphibole parallel to S_2 . This probably represents a recrystallization of earlier amphibole.

Zoisite:

Zoisite is included in albite and it thus related to S I.

CHRONOLOGICAL SEQUENCE OF MINERAL CRYSTALLISATION

	S ₁			S ₂		S ₃
	pre tectonic	syn tectonic	post pre tectonic	syn tectonic	post tectonic	
QUARTZ	—	—	—	—	—	—
MUSCOVITE		—		—	—	
BIOTITE		—		—	—	
GARNET	—	—				
ALBITE			—			
KYANITE		—				
AMPHIBOLE		— ? — ? —		—	—	
ZOISITE		— ? — ? —				
CHLORITE	— ? —	— ? —			—	—
TOURMALINE			—		—	

Fig 10.

RELATION BETWEEN METAMORPHISM AND STRUCTURE (cont.)

Chronological Sequence of mineral Crystallisation.

The time relations between mineral development and the tectonic activity can be deduced from the petrographic features outlined above. Figure (10) is a graphical presentation of the chronological sequence of mineral growth and the tectonic fields of the crystallisation of individual minerals.

The Franklin Group is polymetamorphic, with two periods of mineral crystallisation each related to the two main tectonic phases.

Metamorphism of the S1 phase:

In the first period appeared those metamorphic minerals which are normally connected with the regional metamorphism^a of a sediment of pelitic composition. The index minerals in their order of appearance^a are chlorite, biotite, garnet and kyanite. This includes the chlorite near the Mary-Franklin contact and the biotite in the Governor River Phyllite. The areal distribution of these minerals is zoned from chlorite in the Mary Group, biotite in the lower part of the Governor River Phyllite, garnet and biotite in the upper part, and garnet and kyanite in the upper part of the Franklin Group. The biotite and garnet isograds, determined by the first appearance of S1 biotite and garnet respectively in thin section are drawn on the map. These isograds must be interpreted carefully since there has been a later phase of intense tectonic transport, which must considerably modify their position, and the width of the zones. However, the important feature is that the garnet isograd is tectonically higher and roughly parallel to the biotite isograd. In other words, the fields of crystallisation of chlorite, biotite, garnet

~~kyanite~~ correspond in both chronological and spatial arrangement with Tilley's zones of progressive regional metamorphism in pelitic rocks.

At this point one fundamental problem arises, namely the reason for the decrease in metamorphic grade with an increase in tectonic depth. The problem involves the significance of inverted metamorphic zones. Harker (1932) and Tilley (1925) attributed the sequence of zoning to a temperature gradient; a conclusion accepted by most petrologists. The increase in temperature was further correlated with a regional uprise of granite magma at depth. A zone of higher metamorphism normally underlies a zone of lower metamorphism according to Harker (1932 P.185). This position may become inverted by subsequent deformations. Elles and Tilley (1934) interpret an inverted zoning in the South West Highlands of Scotland where the garnet zone overlies the biotite zone, as due to metamorphism followed by recumbent folding of the zoning. Although the validity of this interpretation is questionable, it would not be unreasonable considering the tectonic environment of the Raglan Range.

However, some workers, notably H.H.Read attribute zoning in general ~~due~~ to metasomatism by advancing fronts. In this case, inversion of zones does not necessarily demand regional overturning since metamorphism can "increase in grade downward, upward or sideways" (1957 P.293) Against Elles and Tilley, Read suggests that mineral crystallisation is post-tectonic and mimetic. This criticism may be valid since the axial surface of the fold in question (Carfick Castle recumbent anticline) is not coincident with the axial surface of the fold in the isograds. Such a criticism cannot be levelled at the Raglan Range since major transport is evident, related to the phyllonite

which formed by retrogression of the S_1 fabric. Furthermore, there is nothing in the chemical analyses to indicate a metasomatic origin of the ferro-magnesium minerals.

Returning to Fig. 10 the other minerals related to the S_1 deformation are amphibole and zoisite. The full importance of crystallisation of amphibole here is not definitely known. The close spatial relationship between first and second generation amphibole, and the association with zoisite (which is definitely S_1) suggests that the knotted amphibole schist and the amphibolites are genetically related. It appears that the basic intrusion was related to the S_1 metamorphism. The post tectonic S_2 amphibole in the amphibolites consequently, would simply represent re-crystallisation related to the S_2 phase.

The sequence of crystallisation has an important bearing on the origin of the albite porphyroblasts. During regional metamorphism on a feldspathic-pelitic sediment or a graywacke albite appears early, in the chlorite zone and then progressively more calcic plagioclase crystallizes alongside biotite and almandine. However, albite has crystallized post-tectonically to S_1 , and later than the biotite and garnet. This is a ~~strong~~ indication that there was no soda present at the onset of metamorphism and suggests a metasomatic origin of the albite.

Nature of the Mayv Group - Governor River Phyllite contact:

The distinction between the Mayv Group and the Governor River Phyllite has been made in two ways. In phyllites (pelitic rocks) the contact is gradational and is taken ~~as~~ as the first appearance of biotite. Albite (type L.) also makes its first appearance very close to the biotite isograd. Biotite appears in small quantities (about 1%) and albite first

appears as minute grains and increases in size and quantity up to the normal mode. There is also a slight increase in grain size.

Secondly the contact is located by the abrupt change from phyllite above and more psammitic rocktypes below. These are the chlorite bearing quartzites and the quartz muscovite schists.

The Governor River Phyllite overlies all members of the succession given on page (12) and so the contact is oblique to the bedding. Outcrop on the valley floor of the Governor River is good in the actual creek beds but elsewhere it is non-existent. The rock distribution of the Mavy Group shown on the map is deduced from traverses down the creeks and interpolation onto the creek divides by projection along the strike, assisted by photo interpretation. The inferred relationship of the bedding (?) in the Mavy Group to the contact is illustrated in the profile. If this contact was purely^a metamorphic boundary, then quartzose bands corresponding to those in the Mavy Group would be expected in the Governor River Phyllite.

Two bands of quartzite are found in the tectonic positions indicated on the profile. These are very similar in appearance to the Mavy Group quartzites but contain albite. These are not in sufficient quantity and not in the correct positions to be the direct structural equivalent to the Mavy Group beds, but ~~surely~~ they have been derived by the soda metamorphism of similar quartzite (Page 30).

The most satisfactory hypothesis concerning the nature of this contact is a metamorphic boundary that has been dislocated by the later tectonic movements.

Metamorphism of the S2 phase:

No new minerals appeared in the second metamorphic period. It involved only the redistribution and recrystallisation of pre-existing minerals such as quartz, muscovite and amphibole and the appearance of chlorite (prochlorite). The S2 biotite appears to be entirely related to the recrystallisation of amphibole. The metamorphism in the whole of the Franklin Group was retrograde.

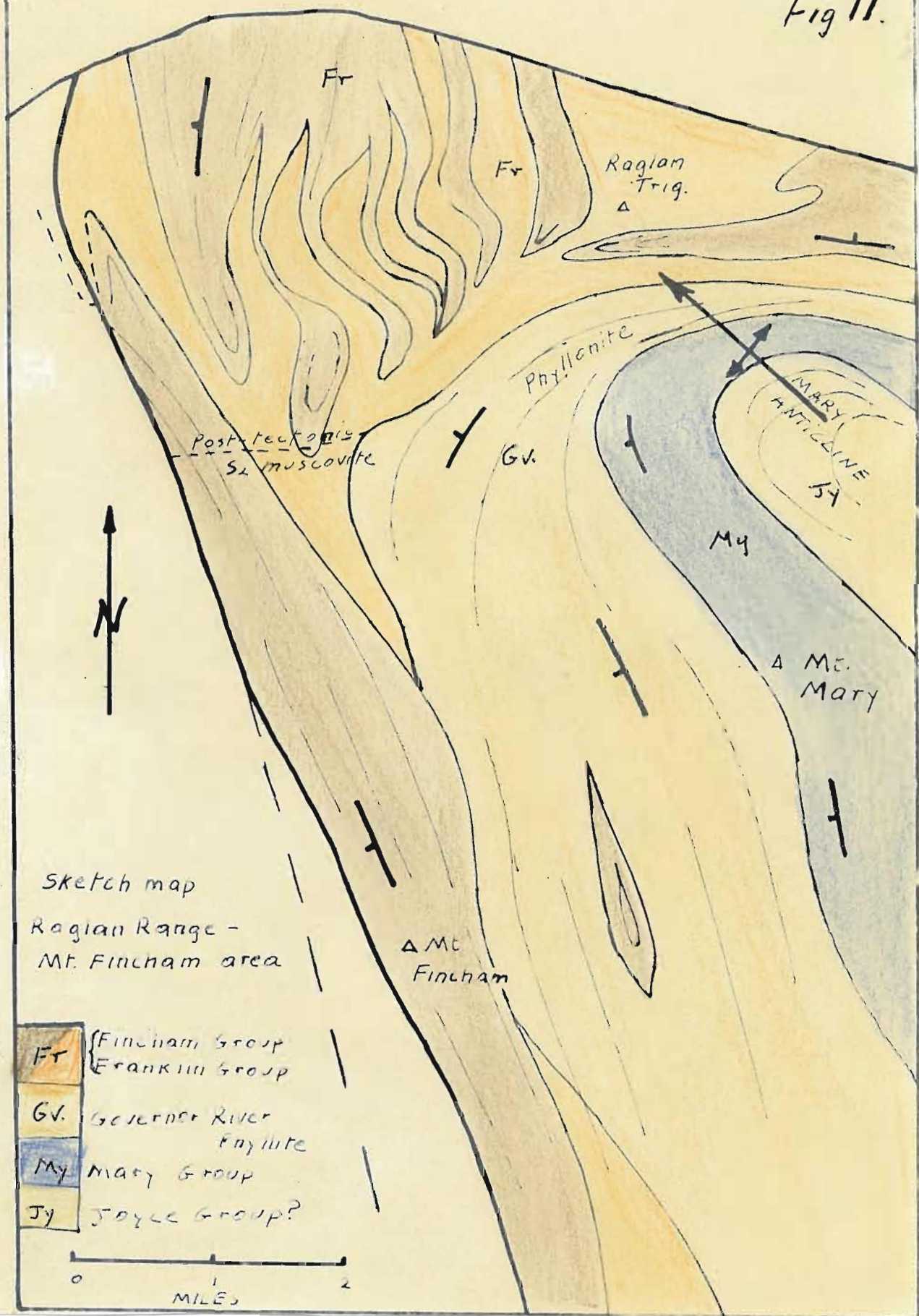
Garnet, kyanite and albite were fractured, sheared and granulated. Syntectonic muscovite crystallised along the new shear planes in the schists, whilst in the quartzite, muscovite grew along the pre-existing shear planes. The amphibolite bodies were remoulded into spheroidal and tabular masses during which the amphibole assumed a new direction of preferred orientation by recrystallisation.

Phyllonitisation occurred in the zone above the Mavy Group, as it was over-ridden by the Franklin Group. At a late tectonic stage, muscovite and chlorite again recrystallised in the upper part of the Franklin Group. These two processes did not affect the zone of phyllonite, thus giving the Governor River Phyllite its distinctive lithology.

The upper limit of the Governor River Phyllite is ^{at} gradational and difficult to locate precisely.

It is determined in the field by the colour change of the weathered rock from dark blue-black to brown and the change from dominantly aphanitic to phanitic. This is the line drawn on the map. This boundary corresponds, in thin section, to the first appearance of mimetic S2 muscovite, and apparently also to the change-over from type I to type II albite. This may be fortuitous.

Fig 11.



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First appearance of mimetic S2 muscovite may not be a necessary marker of this contact and probably does not apply in McLeod's (1957) area to the south of the Raglan Range. Schists contained within the Fincham quartzite do not contain mimetic S2 muscovite (writer's observation of McLeod's specimens). This muscovite horizon probably continues to the south west and does not swing to the south ~~in area~~ as shown on Fig 11. It is suggested that this is one of the important, if not the only difference between the Franklin Group and the Fincham Group. The effect of the S1 metamorphism on the Fincham Group is not known, but McLeod reports garnet schists associated with the quartzites.

Tectonics of the Area.

The area covered in this report is not sufficiently large to give an indication of the tectonics, except for a suggestion of large-scale overturning. (Fig. 11) is a sketch map combining the essential features of the Raglan Range with the rock distribution of the Mt. Fincham area.

The following correlations are made, based on structural continuity. Lithological similarity is a help, but should not be relied upon.

- i. Governor River Phyllite with Canyon Creek type.
- ii. The Franklin Hut Type and the Fincham Group together taken as equivalent to the coarse Franklin Group schist and quartzite on the Raglan Range.
- iii. The Mavy Group in the valley of the Governor River with the Mavy Group at Mt. Mavy.
- iv. The phyllite that underlies the Mavy Group at the Governor River is possibly the Joyce Group that underlies the Mavy Group at Mt. Mavy.

All faults are eliminated and mostly minor changes are made to McLeod's Map. The coarse Franklin Group schists (Franklin Hut Type) lying south of the Canyon Creek when Unfaulted is assumed to overly the Canyon Creek type in the manner shown in Fig. 11. The Franklin Group appears to be a series of quartzites and schists that have been piled up into recumbent folds and nappes that have over-ridden the Mavy Group. Shearing did not take place on one discrete surface, but was dispersed in a thick zone corresponding to the phyllonite. The direction of tectonic transport is not clear. McLeod (1953) believed the Fincham Quartzite to be a thrust block that has moved to the southwest. The writer is inclined to agree but not for the same reasons. The sense of movement can only be deduced from the overall tectonics and not from minor structures.

The critical area for examination, in order to expound upon this hypothesis of nappe structures lies to the east and north of the Raglan Range which unfortunately is partially occupied by down faulted Palaeozoic sediments.

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- metamorphism*

PLATES

- PLATE I a, b. Glacial cirques
 c. Glacial striations
 c. Fluvio-glacial deposits
- PLATE II a, b. Fold mullions
 c. Irregular mullions
 d, e, f. Quartz rods
- PLATE III a, b, c, d, e, f. Profiles of folds
 in Franklin quartzite.
- PLATE IV a, b, c. Profiles of folds in Frank-
 lin Group Schists.
 d. Boudinage quartz vein.
 e. Amphibolite body
 f. Boudinage in Mary quartzite
- PLATE V a. a-c joints
 b, c, d. Tabberabberan minor folding
- PLATE VI a, b. S₀, S₁ and S₂ in Mary Phyllite
 c. Remnant S₁ and dominant S₂ in
 Mary Phyllite
 d. S₁, S₂, S₃ in Mary Phyllite.
 e. S₂, S₃ in Mary Phyllite
 f, g. S₁ and S₂ in Governor River
 Phyllite
- PLATE VII a. Syntectonic S₁ garnet, post-tectonic
 S₂ muscovite
 b. Post tectonic S₁ albite, original
 S₂ muscovite, Syntectonic garnet.

- b, c. Syntectonic and post tectonic S1 garnet.
- d. Type 3 garnet. See page 101
- e. Albite schist with fragmented garnet.
- f. Albite porphyroblast
- g. Post tectonic S2 muscovite
- h. Porphyroblastic biotite
- i. Albite Porphyroblast with two Si.
Inclusions are of zoisite and biotite.

PLATE VIII

- a. Overturned current bedding in Franklin Quartzite. Page 37.
- b. Pseudo ripple-mark in Franklin quartzite.
- c. Tabberabberan chevron folds